SCHOOL OF CIVIL ENGINEERING

JOINT HIGHWAY RESEARCH PROJECT

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A COST-EFFECTIVENESS APPROACH FOR THE EVALUATION OF HIGHWAY SAFETY IMPROVEMENTS IN THE STATE OF INDIANA

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PURDUE UNIVERSITY
INDIANA STATE HIGHWAY COMMISSION

80-11

Final Report

A COST-EFFECTIVENESS APPROACH FOR THE EVALUATION OF HIGHWAY SAFETY IMPROVEMENTS IN THE STATE OF INDIANA

TO: Harold L. Michael, Director
Joint Highway Research Project

FROM: K. C. Sinha, Research Engineer
Joint Highway Research Project

August 26, 1980

Project: C-36-73J

File: 3-4-10

Attached is the Final Report on the JHRP Study titled "A Cost-Effectiveness Approach for the Evaluation of Highway Safety Improvements in the State of Indiana". Mr. Taro Kaji, Graduate Instructor in Research, conducted the study and authored the report under my direction and with my assistance.

The purpose of the study was to develop a cost effectiveness approach for evaluation of safety improvement projects, development of a procedure for optimal allocation of funds available for safety improvement projects, and illustration of the use of the methodologies using Indiana data. All of these objectives were achieved and are detailed in the report.

The Final Report is submitted for acceptance as fulfillment of the objectives of the research.

Sincerely,

K. C. Sinha

K. C. Sinha
Research Engineer

KCS:ms

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by

Taro Kaji
Graduate Instructor in Research

Joint Highway Research Project

Project No.: C-36-73J

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Purdue University
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ABSTRACT

Kaji, Taro. M.S.C.E., Purdue University, December, 1979. A Cost-Effectiveness Approach for the Evaluation of Highway Safety Improvements in the State of Indiana. Major Professor: Kumares C. Sinha.

A cost-effectiveness approach has been developed for the evaluation of highway safety improvement projects. An application of this approach is presented using data from a group of safety projects conducted during the past few years in the State of Indiana. A model was then formulated to determine optimal budget allocation for safety improvement program taking into consideration multi-year time frame and stochastic characteristic of accident reduction effects and of safety improvement costs.

A cost-effectiveness approach is suggested because it can incorporate non-priceable secondary effects with direct safety impacts of a project. The use of an appropriate cost-effectiveness matrix is recommended to provide necessary data for decision making. On the basis of available data in Indiana, modernization of signal or of flashing beacon was found to be most cost-effective. In addition, accident reduction effects of projects with single safety improvement were observed to be lower than those of projects with double safety improvements.

The model of optimal budget allocation for safety improvements can be successfully used to answer the question, "What, when and where safety improvement alternatives be implemented in order to maximize the reduction of total accidents on an areawide basis, subject to the total funding constraints?" The model results can also be used to determine the optimal funding level necessary in order to maximize cost-effectiveness of an areawide safety improvement program.

CHAPTER I

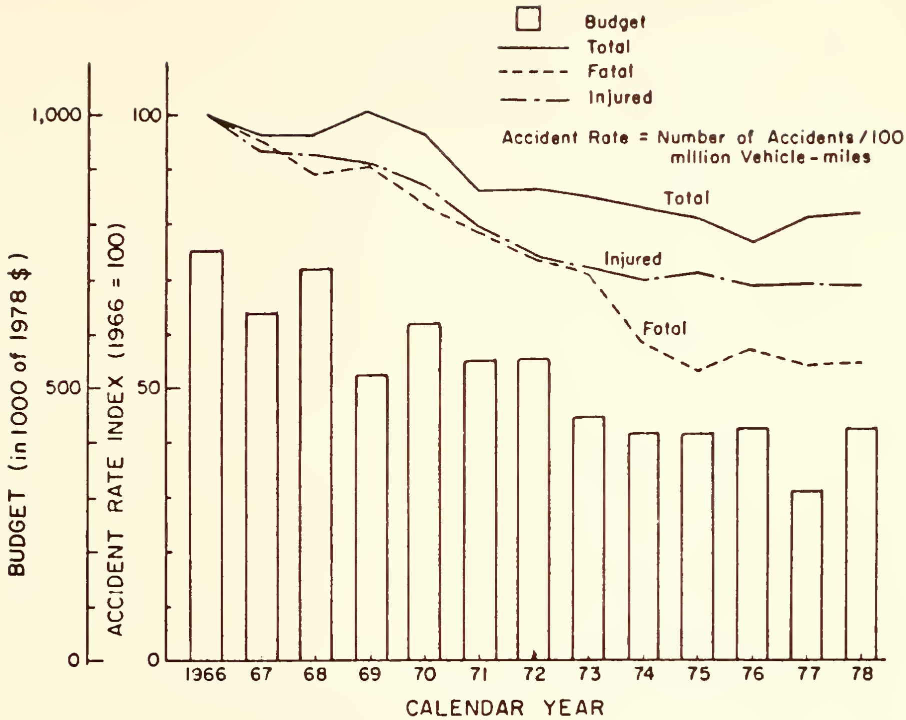
INTRODUCTION

Since the enactment of The Federal Highway Safety Act of 1966, a considerable amount of funding has been made available for highway safety improvement programs. However, in many cases the selection of safety improvement projects has not followed any systematic framework, as indicated by a recent report by the GAO (General Accounting Office) (1). According to this report, most states are still unable to "rank all safety projects according to cost-effectiveness." Some states do not make cost-effectiveness analyses of any type of safety improvement, although it has been required by law for several years (2).

For the purpose of optimal use of safety improvement funds, it is essential to apply a procedure that can evaluate all possible safety improvement alternatives on the basis of cost-effectiveness analysis.

1.1. Highway Traffic Accidents and Budgets Concerning Highway Safety Program in the State of Indiana.

Figure 1.1 shows the trends in motor vehicle traffic accident rates and budgets concerning highway safety programs in the State of Indiana. In this Figure total accident rate includes property damage accidents. The year of 1966, the year in which the Federal Highway Safety Act was enacted, was taken as the base year with accident index



Source: References 3 and 4

Figure 1.1 Trends in Accident Rate Index and Safety Program Budget in Indiana.

value of 100. The amounts of both contract obligation outstandings and contractual awards for construction, reconstruction, betterments and major maintenance were considered to be budgets concerning safety programs. These amounts were transformed to the dollar value of 1978, using Indiana Highway Bid Price Index. (Details of computation are given in Tables A.1 and A.2 in the Appendix). With the implementation of the Highway Safety Act, fatal and injury accidents rates generally decreased from 1967 to 1974. However, both rates have stopped decreasing further since 1974. In fact, the total accident rate has started an upward trend in recent years. At the same time the safety program funding has continued with an amount of more than 250 million dollars for each year since 1966. It is evident that the safety projects implemented through the Highway Safety Act have produced effective results even though the safety projects might not have been always selected on a cost-effectiveness basis. The highway safety situation previous to 1974 was so acute that even an indiscriminate selection and implementation of safety projects could cause a safety improvement. But, as the accident rate information since 1974 indicates in Figure 1.1, indiscriminate implementation of traffic safety projects can no more be considered effective. After the initial improvement in safety has taken place, any further incremental improvement will require a careful and systematic approach to achieve cost-effectiveness.

1.2. Highway Safety Management System.

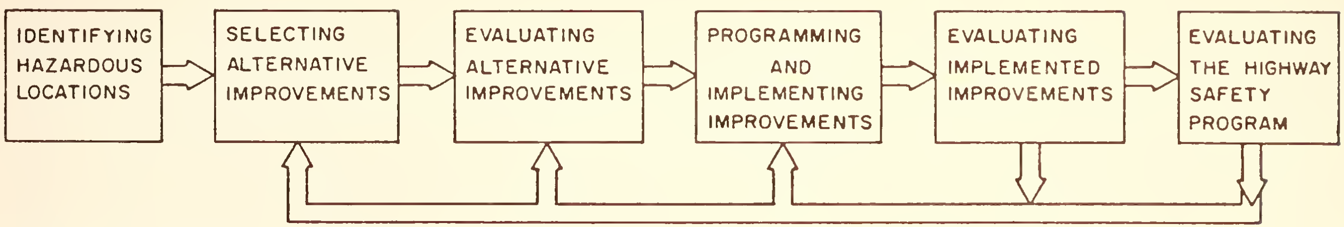
The 1975 Transportation Research Board publication entitled, "Methods for Evaluating Highway Safety Improvements" provides the concepts of highway safety management system (5). The management system for carrying out the safety improvement program consists of steps shown in Figure 1.2. A brief outline of these steps is presented below.

Identifying Hazardous Locations. In this step are identified those locations on the highway system which may be hazardous, and for which some type of safety improvement might significantly reduce the number or severity of accidents. Identification can be based primarily on actual accident experience.

Selecting Alternative Improvements. In this step the locations are analyzed to determine probable causes and to prescribe alternative improvements which will correct conditions.

Evaluating Alternative Improvements. This step is to evaluate alternatives and to select the best one.

Programming the Implementing Improvements. This step is to place the highway safety improvement program in proper perspective and to establish program coordination, implementation, responsibilities, budgeting and scheduling effectively to realize the program objective. Normally, this will involve top-level management decision.



Source: Reference 5

Figure 1.2. Highway Safety Management System.

Evaluating Implemented Improvements. This step is to make adequate follow-up and evaluation of the actual results of implemented improvements.

Evaluating the Highway Safety Program. This step is to evaluate the total safety program in terms of total effectiveness, appropriateness of objectives, and criteria and procedures. In addition to a detailed safety management system description, the NCHRP Report 162 also documented various methods. of evaluating safety improvement programs (5).

In general, there can be several methods for evaluation of safety improvement projects, as shown in Table 1.1. Evaluation methods based on costs or benefits can only be used when the benefits or costs from various alternatives are approximately equal. These methods are in most cases inapplicable to evaluating alternative safety improvement projects. Evaluation methods based on both costs and benefits have been developed in several previous studies. An example of this approach is the procedure developed by Brown et al. in the State of Alabama (6), where a cost-benefit optimization model is employed. However, the problem of establishing traffic accident costs is difficult and any procedure based on dollar values of accident costs can often be misleading. In reality, the actual cost of a traffic accident cannot be measured in monetary terms, because an accident cost figure cannot include the psychological effect of an accident on drivers, passengers, and their families.

Table 1.1. Methods for Evaluation of Safety Improvement Projects.

1. Evaluation Methods Based on Costs

2. Evaluation Methods Based on Benefits

3. Evaluation Methods Based on both Costs and Benefits

   a. Method of Benefit/Cost Ratio

   b. Method of Rate of Returns

   c. Method of Net Annual Benefit

   d. Method of Net Present Worth

4. Evaluation Methods Based on Cost-Effectiveness

In this context a cost-effectiveness approach is more desirable, because this approach attempts to answer the question, "How much does it cost to save one life, or one injury accident, or one accident?" Leininger used cost-effectiveness approach to provide a method for optimal allocation of highway safety budgets (7). But his research did not deal with the evaluation of safety improvement projects; it did not attempt to answer the question, "Where and what kind of safety improvements should be installed?" He showed how to allocate highway safety budgets for driver education, public safety, and highway expenditures, as a case study of Maryland counties.

Safety improvements, in some cases, may have other impacts involving delay at intersections, energy consumption and level of automobile emission. Because some of these consequences are noncommensurable, a benefit-cost approach based on monetary values cannot be used in making a comprehensive evaluation of safety improvement projects. Cost-effectiveness approach, on the other hand, is appropriate in this case.

The principal difference between benefit-cost approach and cost-effectiveness approach is that benefit-cost approach has decision criteria in terms of costs for fatal, injury and property damage accidents, while cost-effectiveness approach does not require monetary values of accidents. Cost-effectiveness approach provides a list of all project costs and

impacts in a tabular form which can be used by the decision makers. This approach therefore offers more flexibility in the use of information about the costs and benefits of projects than that given by benefit-cost approach.

1.3. Purpose of the Study.

The purpose of this study can be summarized as follows:

1) Development of a cost-effectiveness approach for evaluation of safety improvement projects.

2) Development of a procedure for optional allocation of funds available for safety improvement projects.

3) Illustration of the use of the methodologies using data from the State of Indiana.

CHAPTER II

DEVELOPMENT OF THE COST-EFFECTIVENESS EVALUATION METHODOLOGY

In this chapter is developed a methodology for cost-effectiveness evaluation of safety improvement projects. Also discussed is the reduction effect of various safety improvement projects on traffic accidents.

In this connection, it has been assumed that the number of accidents is proportional to the length of survey period and to the amount of traffic volume.

2.1. Basic Concepts of Cost-Effectiveness Approach.

The basic concepts of the cost-effectiveness approach developed in this study are discussed in the following paragraphs.

2.1.1. Effectiveness Measures in Safety Evaluation.

Effectiveness measures to be considered can be enumerated as follows:

1) Number of fatal accidents reduced
2) Number of injury accidents reduced
3) Number of total accidents reduced including property damage accidents

These measures represent the number of fatal, injury or total accidents per year reduced as a result of the installation of a safety improvement project. These measures can be defined by the following equation:

$$\delta = n_b \frac{Q_a}{Q_b} - n_a \tag{2.1}$$

where,

δ : reduction in average number of accidents per year due to the installation of a safety improvement project

n_b : average number of accidents per year before installation of the safety improvement project

n_a : average number of accidents per year after installation of the safety improvement project

$Q_b \cdot Q_a$: average daily traffic volumes before and after the installation, respectively.

In the step of evaluating alternative safety improvement projects, the value of n_a can be estimated as follows:

$$n_a = n_b \frac{Q_a}{Q_b} (1-r) \tag{2.2}$$

where,

r: reduction rate of safety improvement projects on fatal, injury, or total accidents. The values of r can be obtained by equation (2.3):

$$r = \frac{R_b - R_a}{R_b} \tag{2.3}$$

where,

R_b, R_a: number of accidents per million vehicles for fatal, injury, or total accidents before and after installation of safety improvement project, respectively.

Therefore, δ can be obtained by substituting equation (2.4) into equation (2.1) as follows:

$$\delta = n_b \frac{Q_a}{Q_b} - n_b \frac{Q_a}{Q_b} (1-r)$$

$$= n_b \frac{Q_a}{Q_b} \cdot r \qquad (2.4)$$

If reduction rates of safety improvement projects on each type of accidents, such as rear-end, head-on, turing movement, sideswiping and so on, are known and severity rates of each type of accidents are also known, δ can be obtained separately for each severity type by the following equation:

$$\underline{\delta} = \frac{Q_a}{Q_b} \underline{S} \cdot \underline{r} \cdot \underline{n}_b \qquad (2.5)$$

where,

$\underline{S}$: the matrix of severity rates of various types of accidents, as shown below

$$\underline{S} = \begin{bmatrix} S_{11} & S_{12} & \cdots\cdots\cdots & S_{1m} \\ S_{21} & S_{22} & \cdots\cdots\cdots & S_{2m} \\ S_{31} & S_{32} & \cdots\cdots\cdots & S_{3m} \end{bmatrix} \qquad (2.6)$$

where,

$\sum_i S_{ij} = 1$

Each row of the matrix refers to fatal, injury or property damage accident, while each row refers to a type of accident.

$\underline{r}$: the matrix of reduction rates for each type of accident, as shown in equation (2.7):

$$\underline{r} = \begin{pmatrix} r_1 & & & 0 \\ & r_2 & & \\ & & \ddots & \\ 0 & & & r_m \end{pmatrix} \qquad (2.7)$$

$\underline{n}_b$: the vector of the number of each type of accidents before safety improvement, as shown in equation (2.8):

$$\underline{n}_b = \begin{pmatrix} n_{b1} \\ n_{b2} \\ \vdots \\ n_{bm} \end{pmatrix} \qquad (2.8)$$

m: total number of accident types considered.

The primary effectiveness measures of a safety improvement project are concerned with a decrease in the number of accidents and their severity. However, the implementation of a safety improvement project may also have other effects. Although these secondary effects may often be negligible compared to the accident reduction, they should also be considered in a comprehensive evaluation process. The possible secondary effects are:

a. Traffic congestion reduced

b. Wear to vehicle components and fuel consumption reduced

c. Higher speed of operation

d. Traffic delay reduced

e. Other effects, such as street crime reduced due to improved lighting in urban areas.

2.1.2. Safety Improvement Costs.

Safety improvement costs consist of the following factors:

1) Initial costs. These include the capital costs for the installation of a safety improvement project.

2) Annual maintenance costs. These are the annual expenses required to keep the safety improvements in operating condition and maintain the original level of service.

3) Residual values. These are the amount recoverable at the end of the service life. For most safety improvement projects, residual values are negligible.

In general, an equivalent uniform annual cost (C_{eq}) during the service life of a safety improvement is established. If the annual costs are uniform through out the period, C_{eq} can be given by equation (2.9):

$$C_{eq} = C_{r\,n}^{\;i} \cdot I - T \cdot S_{f\,n}^{\;i} + K \tag{2.9}$$

If the annual maintenance costs vary from year to year, C_{eq} can be given by equation

$$C_{eq} = C_{r\,n}^{\;i} \left[I + \sum_{j=1}^{n} K_j \cdot P_{w\,j}^{\;i}\right] - T \cdot S_{f\,n}^{\;i} \tag{2.10}$$

where

$C_{r\,n}^{\;i}$: capital recovery factor for n years at an interest rate of i

$P_{w\,j}^{\;i}$: present worth factor for each year at an interest rate of i

$S_{f\,n}^{\;i}$: sinking fund factor for n years at a discount rate of i

I : initial cost of a safety improvement project

K, K_j: uniform annual maintenance cost and annual maintenance cost for the jth year, respectively

T : residual value of a safety improvement project

n : service life of improvement.

Evaluation of alternative safety improvement projects requires the establishment of these costs. However, the difference of read conditions, traffic conditions, and environment of locations make these estimations difficult. A statistical approach is therefore generally taken to establish the appropriate costs of various safety improvement projects.

2.1.3. Cost-Effectiveness of Safety Improvement.

One approach to evaluate the cost-effectiveness of alternative safety improvement projects is to consider the appropriate values for cost per fatal accident reduced, cost per injury accident reduced, or cost per accident (all accidents) reduced. These values can be obtained by dividing equivalent uniform annual cost of a safety improvement project by the expected number of annual reductions in fatal, injury or total accidents, as shown in equation (2.11):

$$\sigma = \frac{C_{eq}}{\delta} \qquad (2.11)$$

where,

σ: the value of cost-effectiveness for fatal, injury or total accidents.

Often it is difficult to quantify the secondary impacts of a safety improvement project. Therefore, these impacts should be considered on a qualitative basis in the evaluation process.

In Table 2.1 is given a suggested matrix format that can be used in making a cost-effectiveness evaluation of various safety improvement projects. The matrix allows an explicit consideration of all possible costs and consequences of a project and thus provides the necessary data for the decision makers.

2.2. Reduction Effects of Safety Improvement on Traffic Accidents.

In this section a procedure to determine accident reduction effects of alternative improvement projects is discussed.

2.2.1. Measurement of Reduction Effects.

Reduction effects of a safety improvement project are necessary to estimate the number of fatal, injury, or total accidents reduced by an installation. Reduction effects can generally be measured in terms of reduction rates as mentioned in 2.1.1.

The types of accident and traffic data that can be obtained related to before and after installation of safety improvement projects are indicated in Table 2.2. Reduction rate of a safety improvement project for location i can then be

Table 2.1. Matrix for Cost-Effectiveness Evaluation of Safety Improvement Project.

		Primary Effect			Secondary Effect				
					++ increases significantly, + increases somewhat 0 negligible or no effect -- reduces significantly, - reduces somewhat				
Safety Improvement Project	Equivalent Uniform Annual Cost $	Accidents Reduced/Year () = Cost per Accdnt			Traffic Congestion	Wear to Vehicle and Fuel Consumption	Speed of Operation	Traffic Delay	Other
		Fatal	Injury	Total					

Table 2.2. Notation for Computation of Accident Rates.

	Before	After
Survey Period (Years)	T_{bi}	T_{ai}
Average Daily Traffic Volume (Vehicles)	Q_{bi}	Q_{ai}
Number of Accidents	n_{bi}	n_{ai}
Accident Rate (Accident/million vehicles)	$R_{bi} = \frac{n_{bi} \cdot 10^6}{T_{bi} \cdot Q_{bi} \cdot 365}$	$R_{ai} = \frac{n_{ai} \cdot 10^6}{T_{ai} \cdot Q_{ai} \cdot 365}$

calculated as follows:

$$r_i = \frac{R_{bi} - R_{ai}}{R_{bi}} \tag{2.12}$$

Equation (2.12) can be rewritten as equation (2.13) by substituting the values of R_{bi} and R_{ai} as shown in Table 2.2.

$$r_i = \left(\frac{n_{bi} \cdot 10^6}{T_{bi} \cdot Q_{bi} \cdot 365} - \frac{n_{ai} \cdot 10^6}{T_{ai} \cdot Q_{ai} \cdot 365} \right) \Bigg/ \frac{n_{bi} \cdot 10^6}{T_{bi} \cdot Q_{bi} \cdot 365} = \frac{n_{bi} - n_{ai} \cdot \frac{T_{bi}}{T_{ai}} \cdot \frac{Q_{bi}}{Q_{ai}}}{n_{bi}} \tag{2.13}$$

If T_{ai} and T_{bi} are not same, n_{ai} should be transformed as shown below:

$$n_{ai}^* = \frac{T_{bi}}{T_{ai}} \cdot \frac{Q_{bi}}{Q_{ai}} \cdot n_{ai} \tag{2.14}$$

Equation (2.13) can then be rewritten as follows:

$$r_i = \frac{n_{bi} - n_{ai}^*}{n_{bi}} \tag{2.15}$$

The mean value of reduction rate of a type of safety improvement project, $\bar{r}$ can be obtained by weighted mean method, as shown below:

$$\bar{r} = \frac{n_{b1} r_1 + n_{b2} r_2 + \cdots + n_{bm} r_m}{n_{b1} + n_{b2} \cdots\cdots + n_{bm}}$$

$$= \frac{\sum_{i=1}^{m} n_{bi} r_i}{n_{b\cdot}} \tag{2.16}$$

where,

m: the number of locations installed with a type of safety improvement project.

$n_{b\cdot}$: total number of accidents before installation of a type of safety improvement projects for all locations.

$$n_{b\cdot} = \sum_{i=1}^{m} n_{bi} \tag{2.17}$$

Consequently, by substituting equation (2.15) into equation (2.16) the following equation can be obtained.

$$\bar{r} = \frac{\sum_i n_{bi} \dfrac{n_{bi} - n_{ai}^*}{n_{bi}}}{n_{b\cdot}}$$

$$= \frac{\sum_i (n_{bi} - n_{ai}^*)}{n_{b\cdot}}$$

$$= \frac{\sum_i n_{bi} - \sum n_{ai}^*}{n_{b\cdot}}$$

$$= \frac{n_{b\cdot} - n_{a\cdot}^*}{n_{b\cdot}} \tag{2.18}$$

where,

$n_{a\cdot}^*$: total transformed number of accidents after installation of a type of safety improvement projects for all locations.

2.2.2. Statistical Characteristics of Reduction Effect.

The number of accidents recorded after installation of a safety improvement project for a given period of time is n_a. If the period of time is different from the survey period for

which the before data was collected, n_a should be adjusted. This adjustment is done by equation (2.14).

The sampling distribution of $n_a{}^*$ can be given by the binomial probability function as follows:

$$f\ (n_a{}^*) = \binom{n}{n_a{}^*} P_a{}^{n_a{}^*} (1 - P_a)^{n - n_a{}^*} \qquad (2.19)$$

where,

P_a: the probability of accidents occurring after installation of safety improvement project under the condition that survey periods and traffic volumes are the same before and after installation of a safety improvement project;

n : all possible accidents $(n_b + n_a{}^*)$.

The distribution of the sample proportion denoted by $\overline{P_a}$ can then be given by the binomial probability function:

$$f\ (\overline{P_a}) = \binom{n}{n.\overline{P_a}} P_a{}^{n.\overline{P_a}} (1 - P_a)^{n\ (1 - \overline{P_a})} \qquad (2.20)$$

where, $\overline{P_a} = n_a{}^*/n$.

The mean and variance of this distribution are given as follows:

$$E\ (\overline{P_a}) = P_a \qquad (2.21)$$

$$\delta^2\ (\overline{P_a}) = \frac{P_a\ (1 - P_a)}{n} \qquad (2.22)$$

If n is large enough, the distribution of $\overline{P_a}$ can follow the normal distribution which has the same mean and variance as equations (2.21) and (2.22).

The relationship between $\overline{P_a}$ and $\bar{r}$, the sample reduction rate of a safety improvement project, is given by:

$$\overline{P_a} = \frac{n_a^*}{n_b + n_a^*}$$

$$= \frac{\dfrac{n_a^*}{n_b}}{1 + \dfrac{n_a^*}{n_b}}$$

$$= \frac{1 - \dfrac{n_b - n_a^*}{n_b}}{1 + 1 - \dfrac{n_b - n_a^*}{n_b}}$$

$$= \frac{1 - \bar{r}}{2 - \bar{r}} \tag{2.23}$$

2.2.3. Test of Significance of Reduction Rates.

Hypothesis for test of reduction effects of a safety improvement project is:

$$\begin{cases} H_0 : r \leqq 0 \\ H_1 : r > 0 \end{cases} \tag{2.24}$$

This hypothesis can be written as follows:

$$\begin{cases} H_0 : \overline{P_a} \geqq 1/2 \\ H_1 : \overline{P_a} < 1/2 \end{cases} \tag{2.25}$$

Therefore, a test can be conducted as follows if n is large enough.

If $\overline{P_a} \geqq A_1 + 1/2$ it can be concluded that H_0 is true indicating that safety improvement project has no reduction effect. Otherwise, H_1 is to be accepted. The value of A_1 is given by equation (2.26):

$$A_1 = z(\alpha) \cdot \sqrt{\frac{\overline{P_a}\,(1 - \overline{P_a})}{n - 1}} \tag{2.26}$$

where

$z(\alpha)$: the notation which represents the 100α percentile of the standard normal distribution.

2.2.4. Prediction of Reduction Effects of Multiple Improvement Projects.

Reduction rates of multiple safety improvement projects cannot often be estimated from observations because of the lack of adequate data. Therefore, it may be necessary to estimate appropriate values as discussed below.

If the reduction rate of each of constituent single improvement projects is known, reduction rate of the multiple safety improvement project can be predicted by the follow equation.

$$r^* = 1 - \prod_{k=1}^{m} (1 - r_k) \tag{2.27}$$

where

r^*: reduction rate of a multiple safety improvement project

r_k: reduction rate of single safety improvement project

k which multiple safety improvement consists of,

m: the number of constituent single safety improvement projects included in the multiple safety improvement.

CHAPTER III

APPLICATION OF COST-EFFECTIVENESS APPROACH FOR SAFETY IMPROVEMENT EVALUATION IN INDIANA

In this chapter a group of safety improvement projects in the State of Indiana are evaluated on the basis of cost-effectiveness approach mentioned in Chapter II. Evaluation has three aspects in highway safety management system; one is to evaluate alternative improvements for a particular location, another is to evaluate the effectiveness of implemented improvements, and the third is to evaluate the entire highway safety program. As the data available were not extensive, the results of this evaluation should be considered only as an example of the use of the prcedures.

3.1. Data Collection.

In the following sections are discussed the type and the extent of data collected and analyzed in this study.

3.1.1. Data Processing.

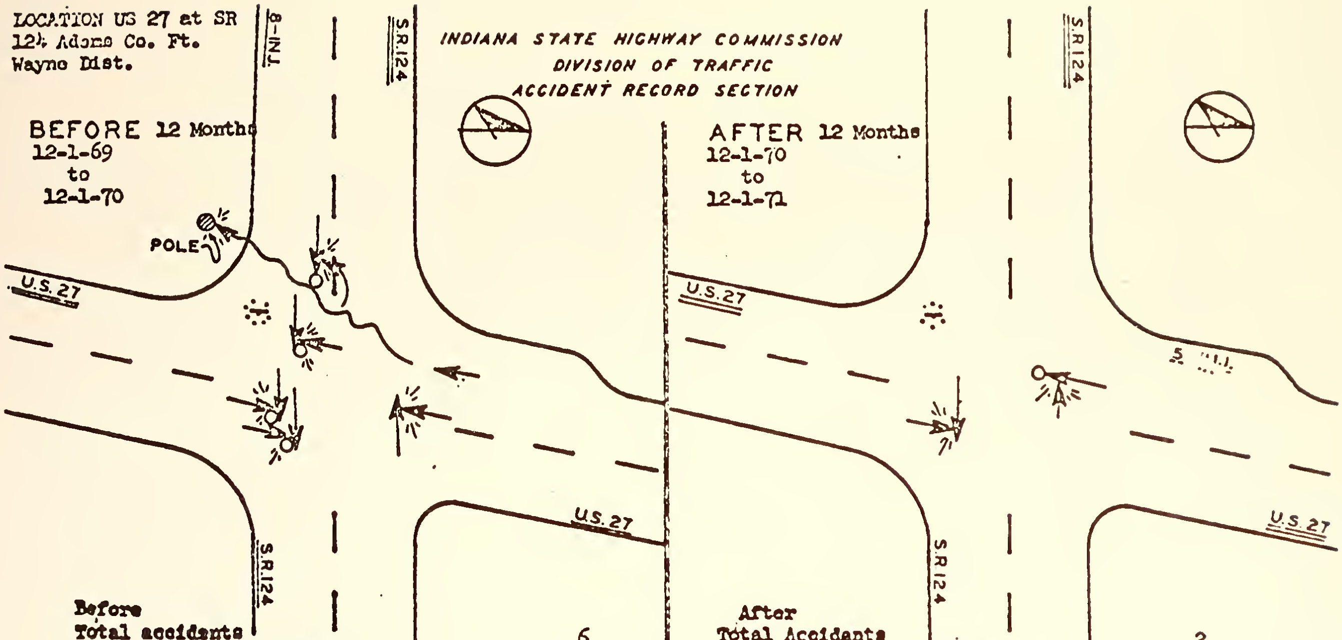
In this study was considered a set of safety improvement projects implemented in Indiana during the past few years for which before and after data were available. The available data were collected and organized by the Indiana State Highway Commission (ISHC) in a before and after survey format shown in Figure 3.1. The types of safety improvement projects included in the data are enumerated in Table 3.1. The data included 182 locations distributed

INDIANA STATE HIGHWAY COMMISSION
DIVISION OF TRAFFIC
ACCIDENT RECORD SECTION

LOCATION US 27 at SR 124 Adams Co. Ft. Wayne Dist.

BEFORE 12 Months
12-1-69 to 12-1-70

AFTER 12 Months
12-1-70 to 12-1-71



Before	
Total accidents	6
Property damage accidents	2
Personal injury accidents	4
Fatal accidents	0
Persons injured	7
Persons killed	0
Day 5 Night 1 · Dry 5 Wet 1.	
Total Property Damage	$ 6275.00

After	
Total Accidents	2
Property damage accidents	1
Personal injury accidents	1
Fatal accidents	0
Persons injured	5
Persons killed	0
Day 2 Night 0 Dry 2 Wet 0	
Total Property Damage	$ 9800.00

THE IMPROVEMENT December 1, 1970 Alternating Flashing Beacon Installation Utilizing all 12" Signal Faces. Estimated Cost $ 3000.00

REMARKS

Figure 3.1 Before and After Survey Format (Example)

Table 3.1. Types of Safety Improvement Project

Intersection Project

1. Sign

   Warning sign installed "Signal Ahead"
   Warning sign installed "Watch for Left Turns"
   Four way stop sign installed
   Two way stop sign installed
   Change speed zone
   Warning "Narrow Bridge"
   Warning "Keep Right"

2. Signal

   Flashing beacon for sign
   Flashing beacon at intersection
   Signal installed
   Change signal face
   Change timing
   Left turn arrow added

3. Channelization

   Left turn lane
   Right turn lane
   Recovery lane
   Remove recovery lane

4. Others

   Illustration for sign
   Widening lane width
   Median barrier
   Illumination
   Flexible guide posts
   Warning flasher
   De-slicking

Table 3.1, cont.

<u>Non-intersection Type Project</u>

Rumble strips

Flasher at nose

Guardrail

Resurfacing

through Indiana, as shown in Table A.3 of the Appendix.

The available data were coded for computer processing in the format shown in Table 3.2. In this format such items as annual maintenance cost, residual value and service life of safety improvement, accident location type, county and traffic growth rate were included in addition to the data given in the ISHC data sheets. Annual maintenance cost, residual value, service life and traffic growth rate were estimated as follows:

1) Annual maintenance cost was taken as (30/n) of initial cost, where n = service life of safety improvement (years). This was based on "Manual on Identification, Analysis and Correction of High Accident Locations." (8)

2) Residual value was considered to be zero.

3) Service life followed Table A.4 of the Appendix.

4) The value for the traffic volume growth rate (Q_a/Q_b) was assumed to be 4% per year.

The data preparation followed the steps shown in Figure 3.2. Careful checking was done to ensure accuracy in coding before the computer analysis was conducted.

3.1.2. Summary of Data.

Because the available data did not include a large number of projects, it was necessary to make a new classification of safety improvements by aggregating several improvement types. The resulting categories are shown in Table 3.3. Table 3.4 shows the number of data by location type and by the year when safety improvement was installed.

Table 3.2. Format for Data Coding.

sequent number	countermeasure: no. of improvements	countermeasure: type of improvements installed: no.1	no.2	no.3	no.4	no.5	initial cost of countermeasure	annual cost of countermeasure	salvage cost (terminal value)	service life	identification: location type	identification: hwy. no. (major): type	hwy. no. (major): no.	county	road cond.: urban or rural	road cond.: no. of lanes: major	no. of lanes: minor	road cond.: median v. or n.: major	median v. or n.: minor	no. of acc.: before	no. of acc.: after	no. of accidents (severity): property damage: before	property damage: after	personal injury: before	personal injury: after	fatal: before	fatal: after	person injured: before	person injured: after	person killed: before	person killed: after	accident type: rear-end: before	rear-end: after	right-angle: before	right-angle: after	side-swipe: before	side-swipe: after	turning-movement: before

Table 3.2, cont.

	accident type								road surface								day/night				accident cost		exposure		
	head-on		out of control		pedest-rian		other		dry		wet		snow/ice		other		day		night				no. of days		ratio of A.A.D.T. between before and after
after	before	after	before	after	before	after	before	after	before	after	before	after	before	after	before	after	before	after	before	after	before	after	before	after	

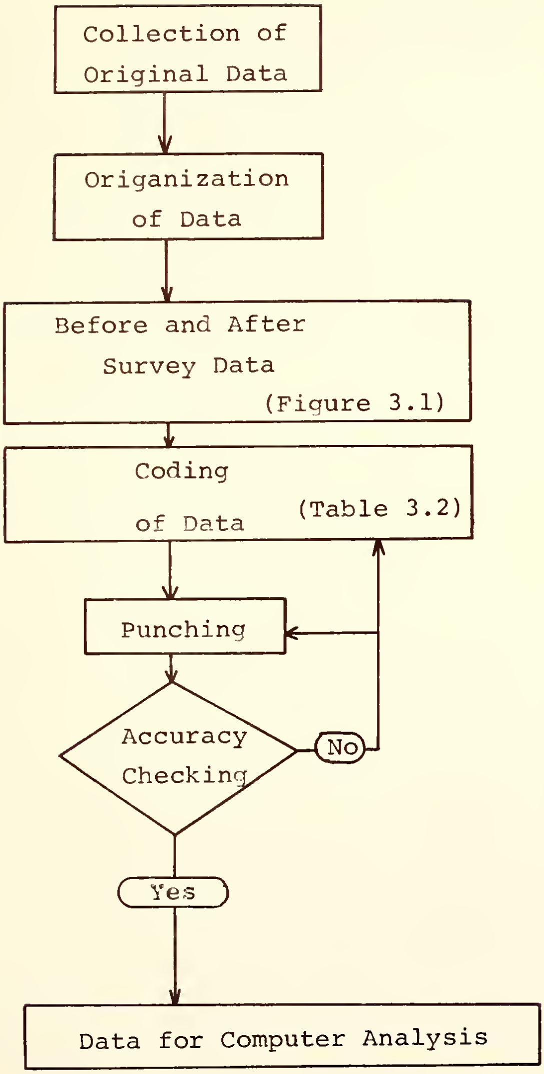


Figure 3.2. Procedure of Preparing Data for Computer Analysis.

Table 3.3. Classification of Safety Improvements Project.

New Category	Initial Category
1) Flashing beacon	Flashing beacon
2) Signal installation	Signal installation
3) Signal modernization	Change signal face Change timing Left turn arrow added
4) Sign	Warning sign Stop sign Regulatory sign
5) Channelization	Left turn lane Right turn lane Recovery lane Remove recovery lane
6) Illumination	Illumination
7) Rumble Strips	Rumble strips
8) Others	Flashing beacon for sign Illumination for sign Widening lane width Median barrier Flexible guide posts Warning flasher De-slicking Flasher at nose Resurfacing Guardrail

Table 3.4. Number of Projects by Location Type and the Year of Installation.

	The Year of Installation											
Location Type	63	64	65	66	67	68	69	70	71	72	Unknown	Total
Intersection	2	6	24	25	14	25	28	27	15	7	1	174
Non-intersection	0	2	0	3	0	0	0	2	1	0	0	8
Total	2	8	24	28	14	25	28	29	16	7	1	182

Almost all data were from intersection projects. A few locations only involved non-intersection type of improvements. The projects considered were installed over a long period, from 1963 through 1972.

Table 3.5 shows the number of locations by safety improvement project. Two-thirds of all projects (127) were single improvement projects. Locations with two simultaneous improvements included 44 projects, while locations with three improvements were only 11. Flashing beacon (48 locations) and signal (48 locations) installations consisted of four-fifths of single safety improvement projects. Largest group of double improvement projects involved signs and flashing beacons.

Table 3.6 provides a summary of accident information on before and after safety improvement by location type. A total of 5302 accidents, including 3456 before and 1846 after, was considered for intersection type of improvements. Seventy-four accidents before and 25 accidents after were involved for non-intersection type improvements. It can be noted in Table 3.6 that the severity of accidents in terms of proportions of fatal, personal injury, and property damage accidents for intersection type was almost the same as for non-intersection type. However, the proportions of accident types were different between intersection type and non-intersection type. At intersection, rear-end (38.2%), right angle (27.4%) and turning-movement (19.8%) were the primary

Table 3.5. Number of Locations by Safety Improvement Type

Safety Improvement Project	Number of Locations
(Single Improvement Project)	
Sign	10
Flashing Beacon	48
Signal Installation	48
Signal Modernization	7
Illumination	4
Rumble Strips	6
Others	4
Subtotal	127
(Double Improvement Project)	
Sign + Flashing Beacon	11
Sign + Signal Modernization	3
Sign + Others	4
Signal Modernization + Channelization	4
Illumination + Others	1
Signal Installation + Modernization	9
Signal Installation + Channelization	4
Signal Installation + Illumination	2
Flashing Beacon + Others	2
Flashing Beacon + Modernization	4
Subtotal	44
(Triple Improvement Project)	
Sign + Flashing Beacon + Others	4
Signal Installation + Modernization + Channelization	2
Signal Installation + Rumble Strips + Others	1

Table 3.5, cont.

Safety Improvement Project	Number of Locations
Signal Installation + Challelization + Others	1
Signal Modernization + Channelization + Others	3
Subtotal	11
Total	182

Table 3.6. Accident Summary Before and After Safety Improvement by Location Type.

Intersection Type

Period	Number of accidents	Severity: Property damage	Personal injury	Fatal	Accident Type: Rear-end	Right-angle	Side-swipe	Turning-movement	Head-on	Out of Control	Pedes-trian	Others
Before	3,456	2,317	1,067	72	1,130	1,119	138	697	49	295	9	19
After	1,846	1,332	496	18	897	331	85	353	31	136	3	10
Total	5,302	3,649	1,563	90	2,027	1,450	223	1,050	80	431	12	29
	(100.0)	(68.8)	(29.5)	(1.7)	(38.2)	(27.4)	(4.2)	(19.8)	(1.5)	(8.1)	(0.2)	(0.5)

Non-intersection Type

Period	Number of accidents	Severity: Property damage	Personal injury	Fatal	Accident Type: Rear-end	Right-angle	Side-swipe	Turning-movement	Head-on	Out of Control	Pedes-trian	Others
Before	74	46	24	4	8	0	3	1	6	56	0	0
After	25	19	6	0	2	0	0	0	4	18	1	0
Total	99	65	30	4	10	0	3	1	10	74	1	0
	(100.0)	(65.7)	(30.3)	(4.0)	(10.1)	(0)	(3.0)	(1.0)	(10.1)	(74.8)	(1.0)	(0)

( ) percentage for number of total accidents

types of accidents. While at the non-intersection type of location, the proportion of accidents for out-of-control (74.8%) was the dominant type.

As for survey periods before and after installation of safety improvements, most of the data had a period of at least one year with only 12 locations with both before and after data for 2 years. (See Table A. 4 in the Appendix). For data analysis all before and after accident data were adjusted to reflect equal time periods for before and after accident survey. It should be pointed out that meaningful accident information should include at least two years of data. Consequently, the results of this study should be viewed only as an example.

3.2. Reduction Rates of Safety Improvement Projects.

The heart of a safety management system lies in the ability to estimate the extent of reduction in numbers or severity of accidents. Therefore, there is a need to update continually and refine approximate reduction rates associated with each of the safety improvement projects.

In Tables 3.7, 3.8 and 3.9 are shown reduction rates of single safety improvements, double safety improvements and triple safety improvements, respectively. The reduction rates, which are significant at 95% level of confidence, are indicated in the Tables. It should be pointed out that many of the reduction rates, particularly for double and triple safety improvement projects, are not reliable, because of

Table 3.7. Reduction Rates of Single Safety Improvement.

	Number of				Reduction rate of					
		accidents			all	accidents				
	data	before	after	after (transformed)	accidents (%)	P. D.	injury	fatal	persons injured	persons killed
Sign	10	247	130	163	34.0*	40.0	23.5	100.0	36.9	100.0
Flashing beacon	48	525	250	358	31.8*	22.9	51.0	96.0	51.0	90.9
Signal Installation	48	1,004	552	774	22.9*	16.2	46.6	61.5	41.1	64.3
Signal Modernization	7	257	144	135	47.5*	43.9	62.7	100.0	62.5	--
Illumination	4	46	33	29	37.0*	37.9	53.3	100.0	67.6	100.0
Rumble Strips	6	98	71	78	20.4	16.1	33.3	100.0	36.8	80.0
Others	4	139	43	39	71.9*	75.0	67.0	50.0	69.8	50.0
Total	127	2,316	1,223	1,576	32.0*	27.9	47.6	86.3	47.2	83.3

-- impossible to compute because $N_b = 0$

* significant at 95% level of confidence

Table 3.8. Reduction Rates of Double Safety Improvements.

* significant at 95% level of confidence

	Number of				Reduction rate of					
		accidents			all	accidents				
	data	before	after	after (transformed)	accidents (%)	P. D.	injury	fatal	persons injured	persons killed
Sign + Flashing Beacon	11	148	36	40	73.0*	71.1	82.4	100.0	85.3	100.0
Sign + Signal Modernization	3	71	52	48	32.4*	20.4	70.0	100.0	69.0	100.0
Sign + Others	4	30	7	5	83.3*	85.7	87.5	100.0	18.2	100.0
Signal Modernization + Channelization	4	199	113	114	42.7*	43.7	41.9	100.0	45.6	100.0
Illumination + Other	1	20	5	9	55.0	41.7	85.7	100.0	22.2	100.0
Signal Installation + Modernization	9	243	121	189	22.2*	17.7	39.1	100.0	43.0	100.0
Signal Installation + Channelization	4	60	37	67	-11.7	-36.1	30.4	100.0	46.0	100.0
Signal Installation + Illumination	2	41	29	54	-31.7	-16.0	-64.3	100.0	-46.7	100.0
Flashing Beacon + Other	2	16	13	11	31.3	-14.3	71.4	100.0	54.5	100.0
Flashing Beacon + Modernization	4	105	28	49	53.3*	52.5	66.7	100.0	62.1	100.0
Total	44	933	441	586	37.2*	33.5	49.6	100.0	50.8	100.0

Table 3.9. Reduction Rates of Triple Safety Improvements.

* significant at 95% level of confidence -- impossible to compute because $N_b = 0$

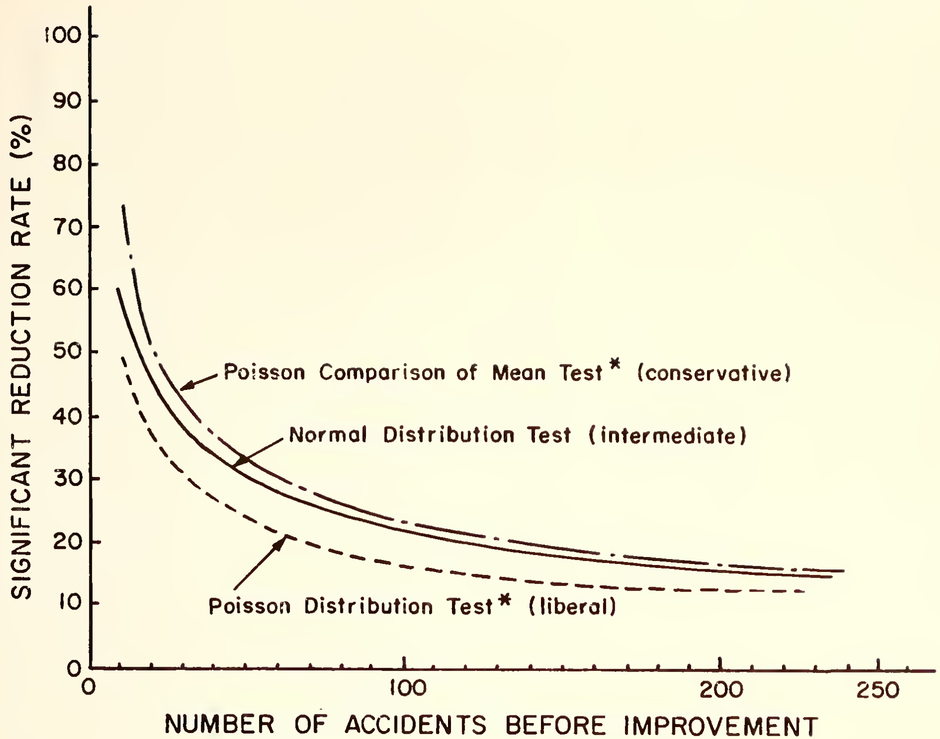
		Number of accidents			Reduction rate of					
	data	before	after	after (transformed)	all accidents (%)	accidents P. D.	accidents injury	accidents fatal	persons injured	persons killed
Sign + Flashing Beacon + Other	4	84	105	148	-76.2	-57.4	-118.8	--	-124.0	--
Signal Installation + Modernization + Channelization	2	46	18	15	67.4*	57.7	85.0	--	77.8	--
Signal Modernization + Channelization + Other	3	127	74	68	46.5*	39.5	65.0	100.0	68.7	100.0
Signal Installation + Rumble Strips + Other	1	9	1	1	88.9	83.3	100.0	100.0	100.0	100.0
Signal Installation + Channelization + Others	1	16	9	8	50.0	33.3	100.0	--	100.0	--
Total	11	282	207	240	14.9*	9.6	36.6	0.0	40.0	0.0

small number of data.

There are several statistical tests of significance of reduction effects of safety improvements (5,9). Reference 5 indicates Poisson comparison of mean test as a "conservative" test and Poisson distribution test as a "liberal" test. In the present study, a test based on normal distribution as discussed in Chapter II, was used. Normal distribution test gives intermediate results between conservative test and liberal test (9). This is illustrated in Figure 3.3.

Of all significant single safety improvement projects signal modernization and illumination indicated high reduction rates of 47.5% and 37.0%, respectively. Among double safety improvements, sign plus flashing beacon, sign plus other improvement, and flashing beacon plus its modernization indicated high reduction rates of 73.0%, 83.3% and 53.3%, respectively. Among triple safety improvements, signal installation plus its modernization plus channelization indicated a high reduction rate of 67.4%. Three of five triple improvement projects did not have significant effect.

On the basis of the given data it can be considered as a whole that double safety improvement projects are more effective than single safety improvement projects. However, triple safety improvement projects are less effective than both single and double safety improvements. However, more accident data of before and after survey for longer periods are necessary before more accurate reduction rates can be



*Source: Reference 5

Figure 3.3. Test of Significance at 95% Level of Confidence.

computed.

3.3. Evaluation of Alternative Safety Improvement Projects for a Location.

3.3.1. Procedure.

Steps for cost-effectiveness approach to evaluate alternative projects for a particular location are shown in Figure 3.4.

3.3.2. Example.

In Tables 3.10 and 3.11 are given an example of cost-effectiveness approach to evaluate safety improvement alternatives for a particular location.

3.4. Evaluation of Significance of Accident Reduction Effects of Implemented Improvements.

3.4.1. Procedure.

Steps to evaluate the reduction effects of the implemented safety improvement projects are shown in Figure 3.5.

3.4.2. Example.

In Table 3.12 is given an example of evaluating the reduction effect of implemented safety improvement projects. The intersection between SR 9 and US 36 (SR 67) in Madison Co., Greenfield District was chosen as an example. In this location a double safety improvement project involving flashing beacon installation and its modernization was

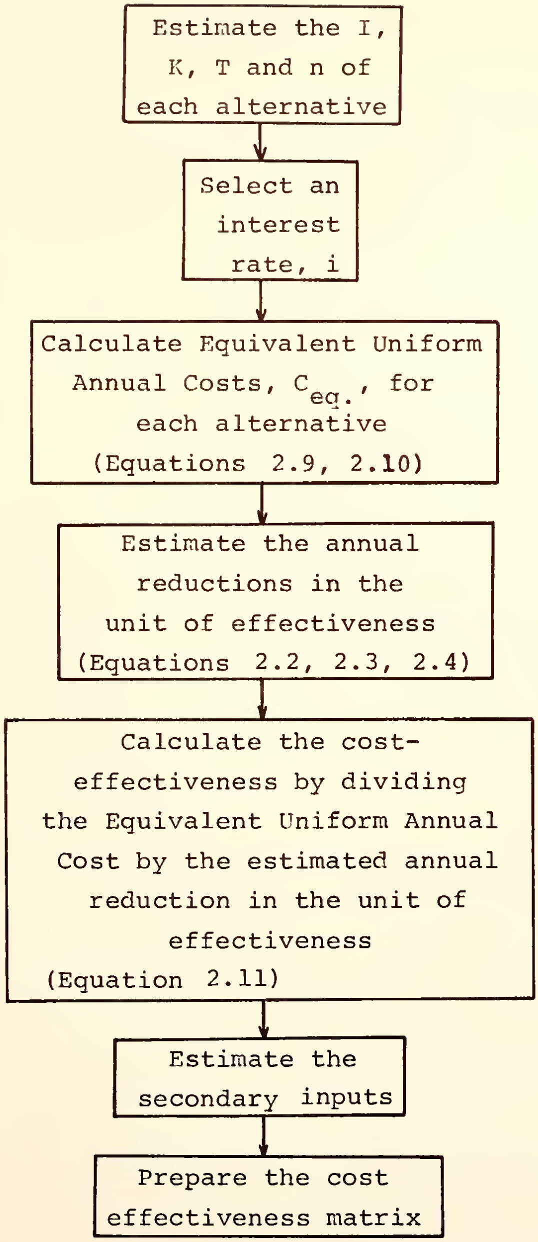


Figure 3.4. Procedure of Cost-Effectiveness Approach to Evaluate Alternatives.

Table 3.10. A Hypothetical Example of Cost Effectiveness Approach to Evaluate Safety Improvement Alternatives.

1), 2) Estimate I, K, T and n, and select i.

Data Item	Channelization	Signalization	Combination
Initial cost	$3,000	$9,000	$12,000
Annual Cost	100	300	400
Residual Value	0	0	0
Service Life	10 years	10 years	10 years
Discount Rate	10%	10%	10%

3) Calculate Equivalent Uniform Annual Cost.

Improvement	C_{eq}
Channelization	$ 588
Signalization	1,765
Combination	2,353

4) Estimate the annual accident reductions.

Annual Accident Reduction	Channelization	Signalization	Combination
Fatal accidents	0	1	2
Personal injury accidents	3	5	8
Total accidents	8	11	16

5) Calculate the Cost/Effectiveness

Cost/ Effectiveness	Channelization	Signalization	Combination
Cost/fatal accidents		$1,765 per accident	$1,177 per accident
Cost/injury accidents	$196 per accident	$ 353 per accident	$ 294 per accident
Cost/total accidents	$ 73.5 per accident	$ 161 per accident	$147 per accident

Table 3.10, cont.

6) Estimate the secondary impact.

Improvement	Traffic Congestion	Wear to vehicle and fuel Consumption	Traffic Delay	Speed of Operation
Channelization	-	-	-	+
Signalization	-	-	-	+
Combination	--	--	--	++

7) Prepare the cost effectiveness matrix (see Table 3.11).

Table 3.11. Cost Effectiveness Matrix of the Example Problem.

Safety Improvement Project	Equivalent Uniform Annual Cost $	Primary Effect: Accidents Reduced/Year () = Cost per Accdnt. Fatal	Injury	Total	Secondary Effect (++ increases significantly, + increases somewhat, 0 negligible or no effect, -- reduces significantly, - reduces somewhat): Traffic Congestion	Wear to Vehicle and Fuel Consumption	Speed of Operation	Traffic Delay	Other
Channelization	588	0 (-)	3 (196)	8 (73.5)	-	-	+	-	0
Signalization	1,765	1 (1,765)	5 (353)	11 (161)	-	-	+	-	0
Combination	2,353	2 (1,177)	8 (244)	16 (147)	--	--	++	--	0

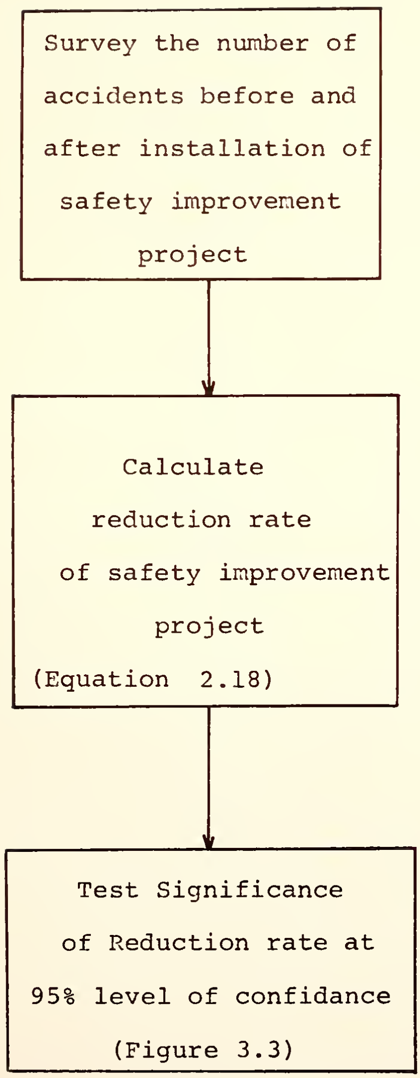


Figure 3.5. Procedure for Evaluating the Implemented Safety Improvement Project.

Table 3.12. Example of Evaluating the Accident Reduction Effect of Implemented Safety Improvement Project.

1) Survey the number of accidents before and after installation.

Location at SR 9, US 36

	Before	After
Survey period	3/10/69-3/10/71 (2 years)	3/10/71-3/10/72 (1 year)
Growth rate of traffic volumes	1	1.04
Number of accidents	56	16

2) Calculate reduction rate.

$$r_n^* = \frac{56 - 16 \times 2 \times \frac{1}{1.04}}{56} = 0.45 = 45\%$$

3) Test significance.

From Figure 3.3, the reduction effect is found to be significant at 95% level of confidence.

installed.

3.5. Evaluation of Statewide Highway Safety Program.

3.5.1. Procedure.

A highway safety program evaluation involves all safety improvement projects in an entire state. Steps for cost-effectiveness approach to evaluate a highway safety program are shown in Figure 3.6.

3.5.2. Example.

A cost-effectiveness matrix for the evaluation of the highway safety program in the State of Indiana is shown in Table 3.13. The data used included only 182 locations for which information was available. Consequently, the example is not a comprehensive analysis of the safety improvement program in Indiana.

Equivalent Uniform Annual Costs were calculated using 1978 dollar values of capital and maintenance costs. A discount rate of 10% was used. Secondary impacts were estimated on a general basis because no actual information could be available.

Modernization of signal and flashing beacon (change signal face, change timing, left turn arrow added, and so on) were observed to be most cost-effective projects according to each item of cost-effectiveness. Other projects which were sufficiently cost-effective include the installation of sign, sign plus other improvement, and so on.

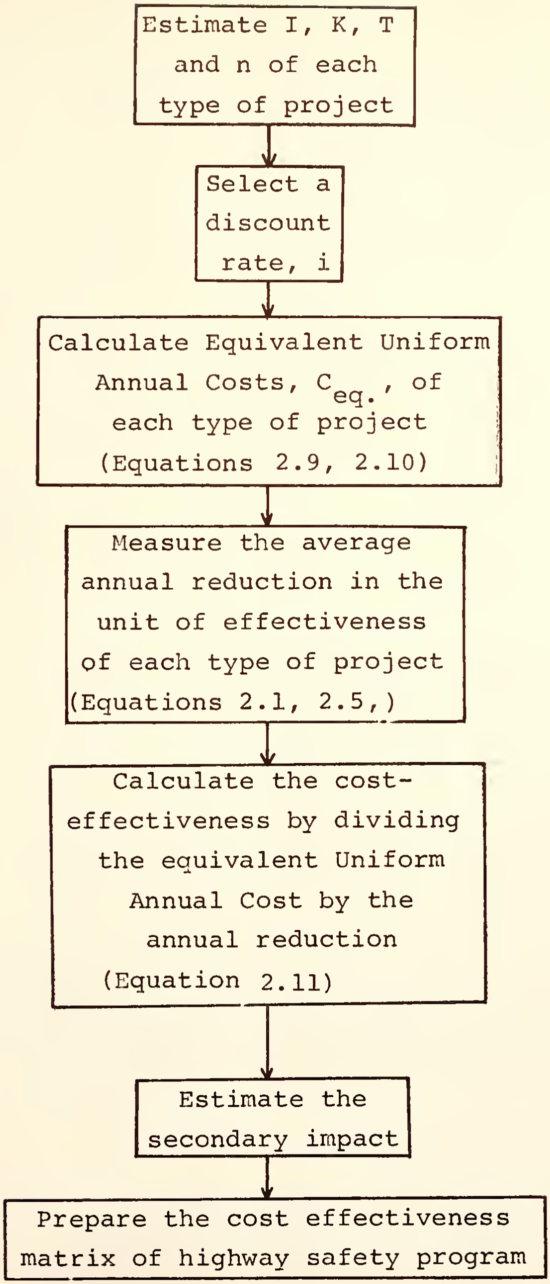


Figure 3.6. Procedure for Cost-Effectiveness Analysis to Evaluate a Statewide Highway Safety Program.

Table 3.13.

Cost Effectiveness Matrix of Highway Safety Program in the State of Indiana.

Safety Improvement Project	No. of Data	Equivalent Uniform Annual Cost $	Primary Effect: Accidents Reduced/Year () = Cost per Accdnt — Fatal	Injury	Total	Secondary Effect (++ increases significantly, + increases somewhat, 0 negligible or no effect, -- reduces significantly, - reduces somewhat): Traffic Congestion	Wear to Vehicle and Fuel Consumption	Speed of Operation	Traffic Delay	Other
Single Flashing Beacon	48	I=291,703 K=8,751 n=10 yr C_{eq}=56226	9 (6,247)	33 (1,704)	74 (760)	-	-	0	-	
Signal Installation	48	I=1,433,335 K=28,667 n=15 yr C_{eq}=220,877	0 (-)	63 (3,506)	121 (1,825)	-	-	+	-	
Sign	10	I=39,211 K=1,176 n=10 yr C_{eq}=7,558	4 (1890)	6 (1260)	47 (161)	0	0	0	0	
Signal Modernization**	6	I=12,966 K=259 n=15 yr C_{eq}=1,964	2 (982)	42 (47)	110 (18)	0	0	+	0	
Illumination	4	I=54,202 K=1,084 n=15 yr C_{eq}=8,210	2 (4,105)	4 (2053)	13 (632)	0	0	+	0	street crime-reduce

Table 3.13, cont.

Safety Improvement Project	No. of Data	Equivalent Uniform Annual Cost $	Primary Effect: Accidents Reduced/Year () = Cost per Accdnt — Fatal	Injury	Total	Secondary Effect (++ increases significantly, + increases somewhat, 0 negligible or no effect, -- reduces significantly, - reduces somewhat): Traffic Congestion	Wear to Vehicle and Fuel Consumption	Speed of Operation	Traffic Delay	Other
Rumble Strips	6	I=18,808 K=2,821 n=2 yr C_{eq}=10,837	0 (-)	5 (2,167)	´8 (1,355)	0	+	0	0	
Other	4	I=36,219 K=1,087 n=10 yr C_{eq}=6,982	1 (6,982)	16 (436)	. 75 (93)					
Double										
Flashing Beacon + Sign	10	I=65,901 K=1,977 n=10 yr C_{eq}=12,702	3 (4234)	24 (529)	54 (235)	-	-	0	-	
Sign + Other	4	I=17,282 K=518 n=10 yr C_{eq}=2813	1 (2813)	2 (1407)	14 (201)					
Sign + Signal Modernization	3	I=12,142 K=364 n=10.yr C_{eq}=2,340	2 (1170)	11 9213)	20 (117)	0	0	+	0	

Table 3.13, cont.

Safety Improvement Project	No. of Data	Equivalent Uniform Annual Cost $	Primary Effect: Accidents Reduced/Year, () = Cost per Accdnt: Fatal	Injury	Total	Secondary Effect (++ increases significantly, + increases somewhat, 0 negligible or no effect, -- reduces significantly, - reduces somewhat): Traffic Congestion	Wear to Vehicle and Fuel Consumption	Speed of Operation	Traffic Delay	Other
Signal Modernization + Channelization	4	I=653,290 K=13,066 n= 15 yr C_{eq}=98,954	0 (-)	16 (6185)	47 (2105)	-	-	++	-	
Rumble Strips + Illumination	1	I=10,661 K=400 n=2 yr C_{eq}=2,398	0 (-)	2 (1199)	5 (480)	0	+	+	0	
Signal Installation + its Modernization	1	I=176,089 K=3,522 n=15 yr C_{eq}=26,672	1 (26672)	6 (4445)	19 (1404)	-	-	++	-	
Signal Installation + Channelization	4	I=306,653 K=6,133 n=15 yr C_{eq}=46,449	0 (-)	0 (-)	-7 (x)	--	--	++	--	
Signal Installation + Illumination	2	I=94,777 K=1,896 n=15 yr C_{eq}=14,356	0 (-)	-7 (x)	-8 (x)	-	-	++	-	street crime reduced

Table 3.13, cont.

Safety Improvement Project	No. of Data	Equivalent Uniform Annual Cost $	Primary Effect: Accidents Reduced/Year () = Cost per Accdnt — Fatal	Injury	Total	Secondary Effect (++ increases significantly, + increases somewhat, 0 negligible or no effect, -- reduces significantly, - reduces somewhat): Traffic Congestion	Wear to Vehicle and Fuel Consumption	Speed of Operation	Traffic Delay	Other
Flashing Beacon + Other	2	I=14,907 K=447 n=10 yr C_{eq}=2,873	2 (1437)	3 (958)	3 (958)					
Flashing Beacon + its Modernization	4	I=20,556 K=617 n=10 yr C_{eq}=3,962	0 (-)	7 (566)	29 (137)	-	-	0	-	
Triple										
Signal Installation + Sign + Other	4	I=147,620 K=4,429 n=10 yr C_{eq}=28,456	-3 (x)	-13 (x)	-33 (x)					
Signal Installation + its Modernization + Channelization	2	I=305,624 K=6,112 n=15 yr C_{eq}=40,180	0 (-)	9 (4464)	37 (2115)	--	--	++	--	

Table 3.13, cont.

Safety Improvement Project	No. of Data	Equivalent Uniform Annual Cost $	Primary Effect: Accidents Reduced/Year () = Cost per Accdnt			Secondary Effect: ++ increases significantly, + increase somewhat, 0 negligible or no effect, -- reduces significantly, - reduce somewhat				
			Fatal	Injury	Total	Traffic Congestion	Wear to Vehicle and Fuel Consumption	Speed of Operation	Traffic Delay	Other
Signal Modernization + Channelization + Other	2	I=513,480 K=1,540 n=10 yr C_{eq}=85,109	0 (-)	11 (7737)	37 (2300)					
Signal Installation + Rumble Strips + Other	1	I=3,385 K=127 n=8 yr C_{eq}=761	0 (-)	1 (761)	3 (254)					
Signal Installation + Channelization + Other	1	I=147,290 K=4,419 n=10 yr C_{eq}=28,390	0 (-)	4 (7098)	7 (4056)					
Total		709,069 (ΣC_{eq})	24 (29,545)	245 (2,894)	657 (1,080)					

Average cost per a fatal accident reduced, average cost per an injury accident reduced, and average cost per an accident reduced (all accidents including property damage accidents) in the State of Indiana were $29,545, $2,894 and $1,080, respectively. These values are considerably lower than the values for average cost per accident reduced shown in the summary of safety costs and benefits of Federal-aid projects (10). Average cost per fatal accident and average cost per total accident of high hazard locations in this summary are $90,000 and $3,000, respectively. A probable reason for this difference is that the projects considered in the present study were implemented during 1963 through 1972, and the information provided in the nationwide summary was for the year of 1976; costs of material and labor have increased at a higher rate in recent years. Nevertheless, it can be considered that highway safety programs in the State of Indiana has been highly cost-effective from 1963 through 1972.

CHAPTER IV

OPTIMAL BUDGET ALLOCATION FOR SAFETY IMPROVEMENT PROJECTS

The cost-effectiveness approach to evaluate safety improvement alternatives for a location has been discussed in Section 3.3 of chapter 3. However, in the process of budget allocation and project scheduling, it is necessary to evaluate alternative improvements for all possible locations simultaneously rather than to evaluate individually. In this chapter a procedure is developed to determine optimal allocation of funding available for safety improvement projects in terms of cost-effectiveness.

In the following sections the model development and its possible applications are discussed through a set of examples.

4.1. The Basic Model.

4.1.1. Formulation of the Basic Model.

In the model, the reduction of total accidents is considered to be the measure of effectiveness. The frequency of total number of accidents is directly related to fatal and injury on a given highway system. Therefore, the reduction of total number of accidents can be taken as the decision criterion. However, if it is desired, the reduction of fatal or injury accidents can be considered as appropriate decision criterion. The constraints of the model is the total funding available for safety improvement projects in

a given year. Then, the optimal allocation of the funding can be obtained by solving the following integer programming problem.

$$\text{Maximize:} \quad \sum_{i} \sum_{j \varepsilon A_i} N_i r_j g_i X_{ij} \tag{4.1}$$

$$\text{Subject to:} \quad \sum_{i} \sum_{j \varepsilon A_i} c_j X_{ij} \leqq B \tag{4.2}$$

$$\sum_{j \varepsilon A_i} X_{ij} \leqq 1 \quad \text{for each } i \tag{4.3}$$

where,

N_i : total number of accidents for location i

r_j : reduction rate of safety improvement project j

c_j : cost of the safety improvement project j

g_i : growth rate of traffic volumes for location i

$$g_i = \frac{Q_{ai}}{Q_{bi}} \tag{4.4}$$

B : total funding available for the entire safety program

X_{ij}: 1, if safety improvement project j is installed at location i;

o, otherwise. (4.5)

$j \varepsilon A_i$: safety improvement project j which is one of the set of alternatives for location i, (A_i).

Equation (4.1) means the objective function, the total number of accidents reduced by the safety program, should be maximized. Equation (4.2) represents the constraint that the total cost of safety improvement projects to be implemented

must not exceed the budget ceiling for the safety program. Equation (4.3) indicates that no more than one safety improvement project can be selected among alternative projects for each location.

It should be pointed out that the model can also be formulated in terms of minimization of system cost-effectiveness ratio. However, the example presented in this study uses reduction of total accidents as the objective function, because it is felt that this criterion is more realistic.

4.1.2. Example.

A hypothetical problem is chosen as an example. Five hazardous locations, for which accident data are shown in Table 4.1, were considered. Alternative improvement projects feasible for each of these locations are shown in Table 4.2. Reduction rates and costs of alternative projects are shown in Table 4.3. It was assumed for this example that the traffic volume does not change and therefore the growth rate is 1.0.

Optimal solutions were obtained for five different budget availability scenarios, with B = 40, 50, 60, 70, and 80 thousand dollars. The results of these five runs are shown in Tables 4.4 through 4.8.

Figure 4.1 shows the trade-off between the number of accidents reduced and total funds required, as obtained from the model. In Figure 4.2 is shown the trade-off between the system cost-effectiveness ratio and total funds required.

Table 4.1. Accident Experiences of Five Locations in the Example Problem

Location	Number of Accidents
1	23
2	15
3	16
4	8
5	10

Table 4.2. Alternative Improvement Projects for Each Location in the Example Problem

Location	Alternative Improvement Projects					
	A	B	C	D	E	F
1	*	*	*			
2		*		*	*	
3			*	*		
4			*		*	*
5	*			*		

Table 4.3. Reduction Rate and Cost of Each Alternative Project in the Example Problem.

Safety Project	Expected Accident Reduction Rate (%)	Cost (Thousand dollars)
A	10	7
B	20	9
C	35	17
D	40	15
E	45	12
F	50	20

Table 4.4. Optimal Solution of Case I (B=$40,000)

Location	Alternative Improvement Projects					
	A	B	C	D	E	F
1	*	(*)	*			
2		*		*	(*)	
3			*	*		
4			*		(*)	*
5	(*)			*		

* Available Alternatives
(*) Alternative Selected

Total Number of Accidents Expected
to be Reduced = 16.0

Cost of All Safety Improvements = $40,000

System Cost-Effectiveness Ratio = $2,500/accident

Table 4.5. Optimal Solution of Case II (B=$50,000)

Location	Alternative Improvement Projects					
	A	B	C	D	E	F
1	*	*	(*)			
2		*		*	(*)	
3			*	*		
4			*		(*)	*
5	(*)			*		

Total Number of Accidents Expected to be Reduced = 19.4

* Available Alternatives

(*) Alternative Selected

Cost of All Safety Improvements = $48,000

System Cost-Effectiveness Ratio = $2,470/accident

Table 4.6. Optimal Solution of Case III (B=$60,000)

Location	Alternative Improvement Projects					
	A	B	C	D	E	F
1	*	*	(*)			
2		*		*	(*)	
3			*	(*)		
4			*		*	*
5	*			(*)		

* Available Alternatives

(*) Alternative Selected

Total Number of Accidents Expected to be Reduced = 25.2

Cost of All Safety Improvements = $59,000

System Cost-Effectiveness = $2,340/accident

Table 4.7. Optimal Solution of Case IV (B=$70,000)

Location	Alternative Improvement Projects					
	A	B	C	D	E	F
1	*	*	(*)			
2		*		*	(*)	
3			*	(*)		
4			*		(*)	*
5	(*)			*		

Total Number of Accidents Expected
to be Reduced = 25.8

Cost of All Safety Improvements = $63,000

System Cost-Effectiveness Ratio = $2,440/accident

* Available Alternatives

(*) Alternative Selected

Table 4.8. Optimal Solution of Case V (B=$80,000)

Location	Alternative Improvement Projects					
	A	B	C	D	E	F
1	*	*	(*)			
2		*		*	(*)	
3			*	(*)		
4			*		*	(*)
5	*			(*)		

Total Number of Accidents Expected
to be Reduced = 29.2

* Available Alternatives

(*) Alternative Selected

Cost of All Safety Improvements = $79,000

System Cost-Effectiveness = $2,706/accident

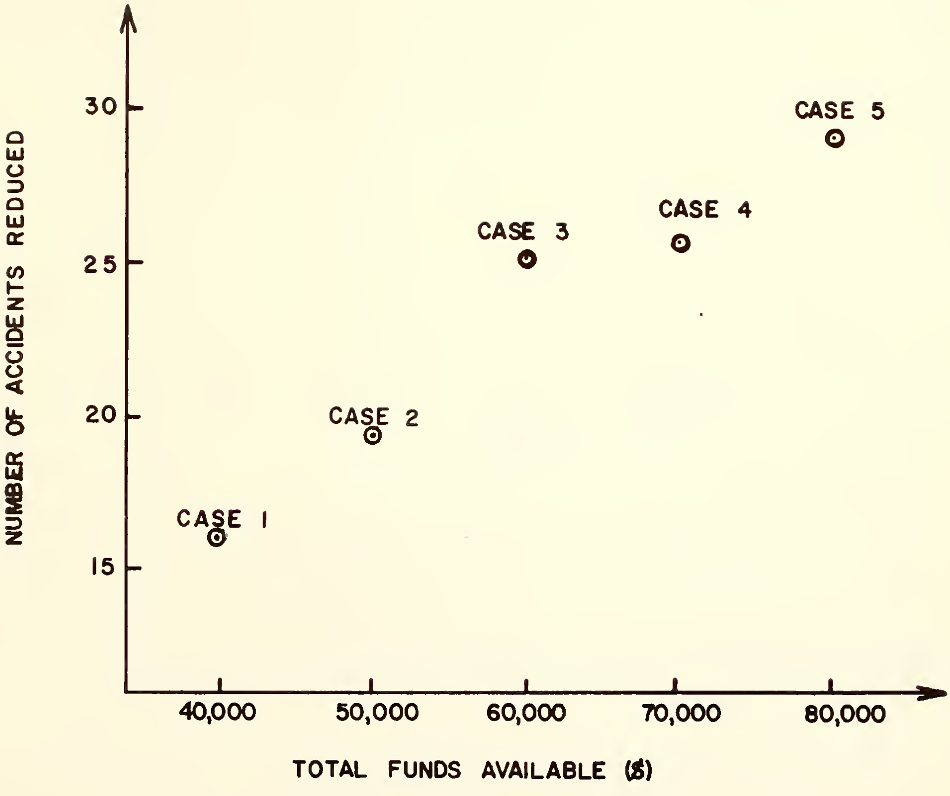


Figure 4.1. Number of Accidents Reduced and Total Funds Available

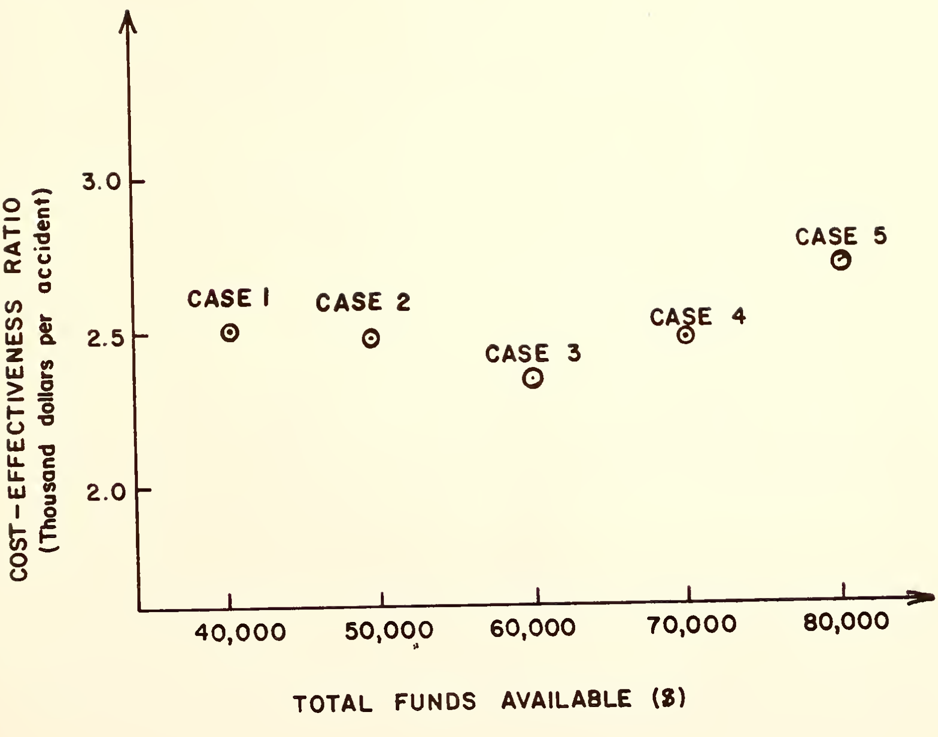


Figure 4.2. Cost-Effectiveness Ratio and Total Funds Available

In Figure 4.1 it can be seen that if the decision criterion is the number of accidents reduced, then funding level of $80,000 is desirable. However, if the system cost-effectiveness ratio is considered to be the decision criterion, funding level of $60,000 is optimal, because at this level cost per accident reduced is the minimum as shown in Figure 4.2.

4.2. Development of the Multi-Year Model

4.2.1. Model Formulation.

A safety improvement program often involves long term-funding and scheduling. Optimal budget allocation for long-term programs should take multi-year programming aspects into consideration. In this section, two types of multi-year model are discussed; one considers no carryover of unspent budget and the other assumes a carryover of unspent budget to the following year.

1) No Carryover of Unspent Budget

This type of multi-year model can be formulated as follows;

$$\text{Maximize:} \quad \sum_i \sum_{j \varepsilon A_i} \sum_t X_{ijt} \, r_j \, g_{it} \, N_i \tag{4.6}$$

Subject to:

$$\sum_i \sum_{j \varepsilon A_i} \left[(X_{ijt} - X_{ijt-1}) \; c_j' + X_{ijt} \, K_j \right] \leq B_t \qquad \text{for all } t \tag{4.7}$$

$$\sum_{j \varepsilon A_i} X_{ijt} \leq 1 \qquad \text{for all } i \text{ and } t \tag{4.8}$$

$$X_{ijt} \geq X_{ijt-1} \qquad \text{for all } i,\ t \text{ and } j\varepsilon(A_i) \qquad (4.9)$$

where,

c_j' : initial cost of safety improvement project

K_j : The annual maintenance cost of safety improvement project j

B_t : Budget ceiling for the t th year.

g_{it}: Growth rate of traffic volume for location i for the t th year.

$$g_{it} = \frac{Q_{it}}{Q_{io}} \qquad (4.10)$$

Q_{it}, Q_{io} : Traffic volume for location i in the t th year and in the year preceding the safety improvement program period.

$$X_{ijt} = \begin{cases} 1, & \text{if project } j \text{ is installed at location } i \text{ in the} \\ & t \text{ th year;} \\ 0, & \text{otherwise} \end{cases} \qquad (4.11)$$

Equation (4.6) represents the objective function to maximize the reduction of the total number of accidents. Equation (4.7) is concerned with the budget ceiling for each year. In this equation, $(X_{ijt} - X_{ijt-1})$ means the following:

$$(X_{ijt} - X_{ijt-1}) = \begin{cases} 1, & \text{if safety improvement project } j \text{ is} \\ & \text{installed for location } i \text{ in the } t \text{ th} \\ & \text{year.} \\ 0, & \text{otherwise.} \end{cases} \qquad (4.12)$$

Equation (4.8) indicates that no more than one alternative project can be implemented at any location in a given year.

Equation (4.9) assures that if an improvement project has already been installed in a previous year, the maintenance task of that particular project will be performed in the current year. The last two equations also imply that, at most, only one alternative project is selected for each location during the whole analysis period.

2) Carryover of Unspent Budget

In this type of multi-year model, it has been assumed that unspent budget can be used in the following year. Therefore, the budget constraint is different from the model with no carryover flexibility. Adding the unspent amount from the (t-1)th year to the right hand side of equation (4.7), the following equation is obtained.

$$\sum_{i} \sum_{j \varepsilon A_i} \left[(X_{ijt} - X_{ijt-1})\, c_j' + X_{ijt}\, K_j \right] \leqq$$

$$B_t + \sum_{t'}^{t-1} \left[B_{t'} - \sum_{i} \sum_{j \varepsilon A_i} \{ (X_{ijt'} - X_{ijt'-1})\, c_j' + X_{ijt'}\, K_j \} \right] \quad (4.13)$$

where,

$\sum_{t'}^{t-1}$: summation from 1st year through (t-1)th year.

Rearranging equation (4.13), the following equation can be obtained.

$$\sum_{i} \sum_{j} \sum_{t'}^{t} (X_{ijt'} - X_{ijt'-1})\, c_j' + X_{ijt'}\, K_j \leqq \sum_{t'}^{t} B_{t'} \quad \text{for all } t \quad (4.14)$$

Equation (4.14) is then the new constraint concerning budget ceiling in solving the carryover type of problem.

4.2.2. Stochastic Model.

In the model formulation discussed so far, average values have been considered for the initial cost (c'_j), annual maintenance cost (K_j), and the reduction rate (r_j) of safety projects. However, these values may have a large variance in some cases. Consequently, models mentioned in 4.2.1. should incorporate the stochastic characteristics of these factors.

The observed values of the costs and reduction rate will have intervals as follows:

$$c'_j\ (1-\alpha_{cj}) \leqq c_{jo} \leqq c'_j\ (1+\alpha_{cj}) \tag{4.15}$$

$$K_j\ (1-\alpha_{kj}) \leqq K_{jo} \leqq K_j\ (1+\alpha_{kj}) \tag{4.16}$$

$$r_j\ (1-\alpha_{rj}) \leqq r_{jo} \leqq r_j\ (1+\alpha_{rj}) \tag{4.17}$$

where,

c'_{jo}, K_{jo}, r_{jo}: the observed values of initial cost, annual maintenance cost, and reduction rate of safety improvement project j, respectively.

$\alpha_{cj}, \alpha_{kj}, \alpha_{rj}$: the percent estimation error of initial cost, annual maintenance cost, and the accident reduction rate of safety improvement project j, respectively.

The values of αc_j, αK_j, and αr_j can be estimated from the sample variance values of initial cost, annual maintenance cost and reduction rate, respectively.

Another variability inherent in policy-making - the level of cost overrun allowable - is also brought into consideration in the stochastic model. This not only changes the right hand

sides of equations (4.7) and (4.14) but also imposes a new constraint on the objective function of the non-carryover case which restricts the total cost of safety program to be less than the available budget plus allowable cost overrun.

Adding all these stochastic characteristics, the multi-year model for the non-carryover case would be as follows:

$$\text{Maximize:} \quad \sum_i \sum_{j \varepsilon A_i} \sum_t X_{ijt}\, r_j(1-\alpha_{rj})\, g_{it}\, N_i \qquad (4.18)$$

Subject to:

$$\sum_i \sum_{j \varepsilon A_i} (X_{ijt} - X_{ijt-1}) \cdot c_j(1+\alpha_{cj}) + X_{ijt} \cdot K_j(1+\alpha_{Kj})$$
$$\leq \theta \cdot B_t \quad \text{for all } t \qquad (4.19)$$

$$\sum_i \sum_{j \varepsilon A_i} \sum_t (X_{ijt} - X_{ijt-1}) \cdot c_j \cdot (1+\alpha_{cj}) + X_{ijt} \cdot K_j(1-\alpha_{Kj})$$
$$\leq \theta \cdot \sum_t B_t \qquad (4.20)$$

and equations (4.8) and (4.9).

Where, θ is the level of cost overrun allowable in percentage and all other terms as defined before.

For the carryover case, the model would be composed of equation (4.18), (4.8), (4.9) and the following:

$$\sum_i \sum_{j \varepsilon A_i} \sum_{t'}^{t} (X_{ijt'} - X_{ijt'-1}) \cdot c_j \cdot (1+\alpha_{cj}) + X_{ijt'} \cdot$$
$$(1+\alpha_{Kj}) \quad \leq \theta \cdot \sum_{t'}^{t} B_{t'} \quad \text{for all } t \qquad (4.21)$$

where,

$\sum_{t'}^{t}$: summation from the 1st year through t th year.

It should be noted here that in the above formulation, only the "worse side" of each c_j, K_j and r_j variation is incorporated in the model. This approximation is appropriate as it is only the increasing cost or decreasing accident reduction rate that is of traffic engineer's concerns. The results so obtained should be conservative and reasonable.

A string of other conditions required by or associated with the policy and objective of the transportation agency can also be formulated as binding constraints and incorporated in the model easily. For example, suppose it is required by policy that a pre-determined percentage of accident reduction should be achieved at each hazardous location at the end of the safety program; then, the following constraints could be used.

$$\sum_{j \varepsilon A_i} \sum_t X_{ijt} \cdot r_j (1-\alpha_{rj}) \cdot g_{it} \cdot N_i \geq \beta \sum_t N_i g_{it} \quad \text{for all } i \qquad (4.22)$$

where, β is the required percentage of accident reduction.

4.2.3. Example: Three-Year Safety Program in an Area.

To illustrate the application of the multi-year model formulations, the following problem is considered.

It is assumed that the study area has seven hazardous locations as shown in Table 4.9. Alternative improvement projects for these locations have been selected as shown in Table 4.10. The reduction rates, initial costs, annual

Table 4.9 Accident Experiences of Hazardous Locations in the Example Study Area

Location	Number of Accidents Per Year
1	23
2	15
3	10
4	8
5	10
6	13
7	9
Total	88

Table 4.10 Alternative Improvement Projects for Each Location in the Example Problem

Location	Alternative Improvement Projects					
	A	B	C	D	E	F
1	*	*	*			
2		*	*		*	
3				*	*	
4				*		*
5		*	*			
6		*		*		*
7	*		*			

maintenance costs and their stochastic characteristics (percent errors) are shown in Table 4.11. It is further assumed that the highway safety division of the area has a three-year safety program of which total budget ceiling is 135 thousand dollars (B_1 = \$35,000, B_2 = \$45,000, B_3 = \$55,000). It can be assumed that the traffic growth rate is 5 percent per year throughout the area. It is required to determine optimal budget allocation for safety improvement projects.

A computer code, MIPZ1, developed by the Department of Agricultural Economics of Purdue University was utilized to solve this example problem (11). MIPZ1 is a zero-one mixed integer programming package capable of solving problems with up to 150 rows and 450 columns. The algorithm employed by MIPZ1 is basically a modified Additive Algorithm of Balas with major modifications involving a recorded enumeration tree and mixed integer capabilities.

Assuming θ = 110%, the example problem was formulated as a pure integer programming problem with 51 variables and 59 constraints (58 constraints for carryover model). Optimal solution obtained by MIPZ1 is shown in Table 4.12 and 4.13. Table 4.12 gives the results of the non-carryover model, while Table 4.13 provides the results of the carryover model. Also included in the Tables are the results from both versions of non-stochastic and stochastic models.

Table 4.11 Reduction Rates, Initial Costs, Annual Maintenance Costs and Their Stochastic Characteristics Associated with Each Alternative Project in the Example Problem

Safety Improvement Project	Reduction Rate		Initial Cost		Annual Maintenance Cost	
	Reduction Rate (%)	Percent Error (α_r)	Initial Cost (thousand $)	Percent Error (α_c)	Annual Cost (thousand $)	Percent Error (α_k)
A	10	±10%	7	±10%	0.2	± 5%
B	20	±15%	9	±10%	0.3	±10%
C	35	±10%	17	±10%	0.6	± 5%
D	40	±10%	15	±10%	0.5	±10%
E	45	±15%	12	±15%	0.4	± 5%
F	50	±15%	20	±15%	0.7	±10%

TABLE 4.12 : OPTIMAL SOLUTION OF MULTI-YEAR MODEL (NON-CARRYOVER TYPE)

LOCATION	ALTERNATIVE	1ST YEAR	2ND YEAR	3RD YEAR
1	A			
	B			
	C	0 *	0 *	0 *
2	B			
	C			
	E	0 *	0 *	0 *
3	D			
	E		0 *	0 *
4	D		0	0
	F			*
5	B		*	*
	C			0
6	B			
	D		0	0
	F		*	*
7	A			
	C			0 *

0 : OPTIMAL SOLUTION OF STOCHASTIC MULTI-YEAR MODEL
* : OPTIMAL SOLUTION OF NON-STOCHASTIC MULTI-YEAR MODEL

CONDITION : B1 = \$35,000   B2 = \$45,000   B3 = \$55,000 θ = 1.1

	STOCHASTIC	NON-STOCHASTIC
NUMBER OF ACCIDENTS EXPECTED TO BE REDUCED	75.3	86.3
COST OF SAFETY IMPROVEMENT PROJECTS FOR 1ST YEAR	\$33,550	\$30,000
COST OF SAFETY IMPROVEMENT PROJECTS FOR 2ND YEAR	\$49,370	\$43,400
COST OF SAFETY IMPROVEMENT PROJECTS FOR 3RD YEAR	\$41,230	\$40,700
TOTAL COST	\$124,150	\$114,100
COST-EFFECTIVENESS RATIO	\$1,650/ACCIDENT	\$1,320/ACCIDENT

TABLE 4.13 : OPTIMAL SOLUTION OF MULTI-YEAR MODEL (CARRYOVER TYPE)

LOCATION	ALTERNATIVE	1ST YEAR	2ND YEAR	3RD YEAR
1	A			
	B			
	C	O *	O *	O *
2	B			
	C			
	E	O *	O *	O *
3	D			
	E		O *	O *
4	D		*	*
	F			O
5	B			
	C		O	O *
6	B			
	D		O	O
	F		*	*
7	A			
	C			O *

O : OPTIMAL SOLUTION OF STOCHASTIC MULTI-YEAR MODEL
* : OPTIMAL SOLUTION OF NON-STOCHASTIC MULTI-YEAR MODEL

CONDITION : B1 = $35,000 B2 = $45,000 B3 = $55,000 θ = 1.1

	STOCHASTIC	NON-STOCHASTIC
NUMBER OF ACCIDENTS EXPECTED TO BE REDUCED	76.2	88.4
COST OF SAFETY IMPROVEMENT PROJECTS FOR 1ST YEAR	$33,550	$30,000
COST OF SAFETY IMPROVEMENT PROJECTS FOR 2ND YEAR	$51,650	$49,600
COST OF SAFETY IMPROVEMENT PROJECTS FOR 3RD YEAR	$45,750	$37,800
TOTAL COST	$130,950	$117,400
COST-EFFECTIVENESS RATIO	$1,720/ACCIDENT	$1,330/ACCIDENT

The Tables indicate the year a particular alternative project is to be installed at each location in order to achieve maximum reduction of total accidents during the analysis period of three years subject to the total budget constaint. The symbol (*) represents the optimal solution of the non-stochastic version, while the symbol (0) indicates the optimal solution of the stochastic version.

In order to further investigate the effects of different budget availability on total number of accidents reduced, more runs were made out of the stochastic model. The following five budget scenarios were considered:

1. B_1=\$15,000; B_2=\$25,000; B_3=\$35,000; Total=\$ 75,000.
2. B_1=\$25,000; B_2=\$35,000; B_3=\$45,000; Total=\$105,000.
3. B_1=\$35,000; B_2=\$45,000; B_3=\$55,000; Total=\$135,000.
4. B_1=\$45,000; B_2=\$55,000; B_3=\$65,000; Total=\$165,000.
5. B_1=\$55,000; B_2=\$65,000; B_3=\$75,000; Total=\$195,000.

Both carryover and non-carryover models were tested against these five budget ceilings under a set of cost overrun level (θ), namely 1.05, 1.10, and 1.15. The results are presented in Tables 4.14 through 4.16.

Each Table shows the results under a specific θ value. For each budget and model type (carryover or non-carryover) combination, the total number of accidents expected to be reduced, total cost of safety program as well as its corresponding cost-effectiveness ratio are tabulated. The results are also plotted for direct comparison as shown in Figure 4.3 through 4.8.

TABLE 4.14 : OPTIMAL SOLUTION OF STOCHASTIC MODEL UNDER FIVE BUDGET SCENARIOS (θ = 1.05)

BUDGET SCENARIO (IN $1,000)	NUMBER OF ACCIDENTS EXPECTED TO BE REDUCED		TOTAL COST OF SAFETY PROGRAM (IN $1,000)		COST-EFFECTIVENESS RATIO (DOLLARS PER ACCIDENT)	
	NON-CARRYOVER	CARRYOVER	NON-CARRYOVER	CARRYOVER	NON-CARRYOVER	CARRYOVER
75 (15,25,35)	44.8	46.6	69.12	77.24	1540	1660
105 (25,35,45)	58.7	59.4	103.65	104.33	1770	1760
135 (35,45,55)	73.1	75.3	133.58	124.15	1830	1650
165 (45,55,65)	78.8	78.8	125.12	124.78	1590	1580
195 (55,65,75)	85.2	86.8	135.53	125.96	1590	1450

TABLE 4.15 : OPTIMAL SOLUTION OF STOCHASTIC MODEL UNDER FIVE BUDGET SCENARIOS (θ = 1.10)

BUDGET SCENARIO (IN $1,000)	NUMBER OF ACCIDENTS EXPECTED TO BE REDUCED		TOTAL COST OF SAFETY PROGRAM (IN $1,000)		COST-EFFECTIVENESS RATIO (DOLLARS PER ACCIDENT)	
	NON-CARRYOVER	CARRYOVER	NON-CARRYOVER	CARRYOVER	NON-CARRYOVER	CARRYOVER
75 (15,25,35)	45.0	47.8	66.29	81.13	1470	1700
105 (25,35,45)	60.6	62.2	109.41	111.55	1810	1790
135 (35,45,55)	75.3	76.2	124.15	130.95	1650	1720
165 (45,55,65)	82.6	84.7	129.68	132.14	1570	1560
195 (55,65,75)	86.8	89.6	142.39	133.12	1640	1490

TABLE 4.16 : OPTIMAL SOLUTION OF STOCHASTIC MODEL UNDER FIVE BUDGET SCENARIOS (θ = 1.15)

BUDGET SCENARIO (IN $1,000)	NUMBER OF ACCIDENTS EXPECTED TO BE REDUCED		TOTAL COST OF SAFETY PROGRAM (IN $1,000)		COST-EFFECTIVENESS RATIO (DOLLARS PER ACCIDENT)	
	NON-CARRYOVER	CARRYOVER	NON-CARRYOVER	CARRYOVER	NON-CARRYOVER	CARRYOVER
75 (15,25,35)	46.8	49.8	74.41	84.76	1590	1700
105 (25,35,45)	64.6	66.9	113.14	118.69	1750	1770
135 (35,45,55)	76.2	77.5	130.95	131.17	1720	1690
165 (45,55,65)	84.7	84.7	132.14	132.22	1560	1560
195 (55,65,75)	89.6	90.8	133.37	140.06	1490	1540

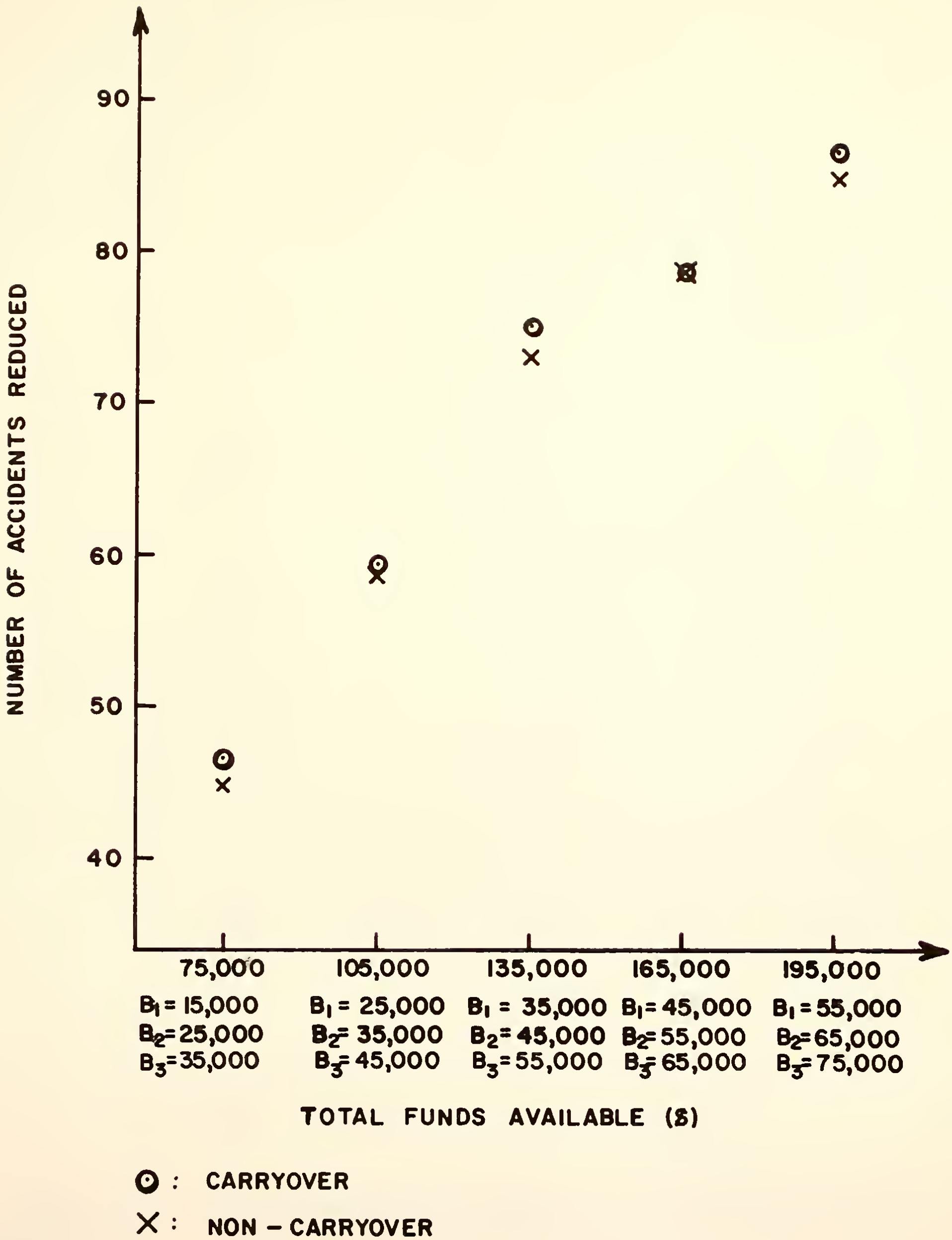


Figure 4.3. Number of Accidents Reduced and Total Funds Available (θ = 1.05)

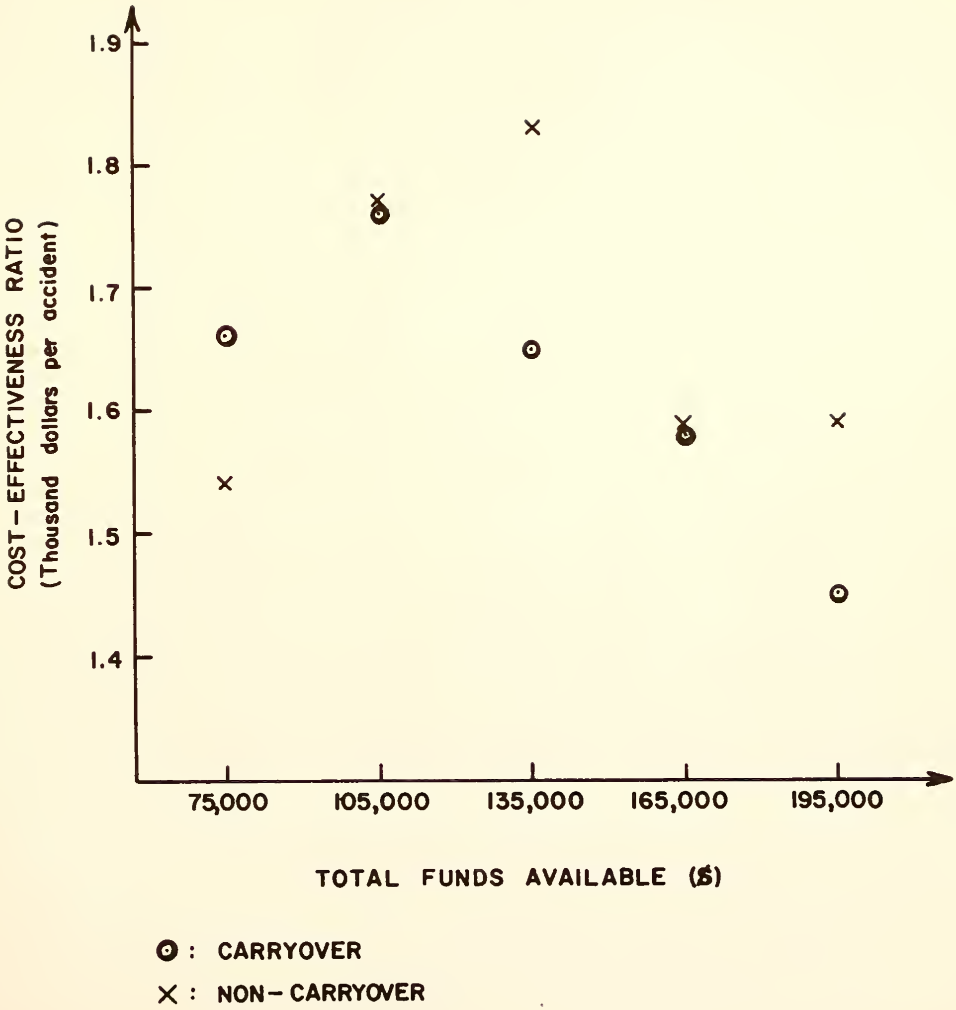


Figure 4.4. System Cost-Effectiveness Ratio and Total Funds Available (θ = 1.05)

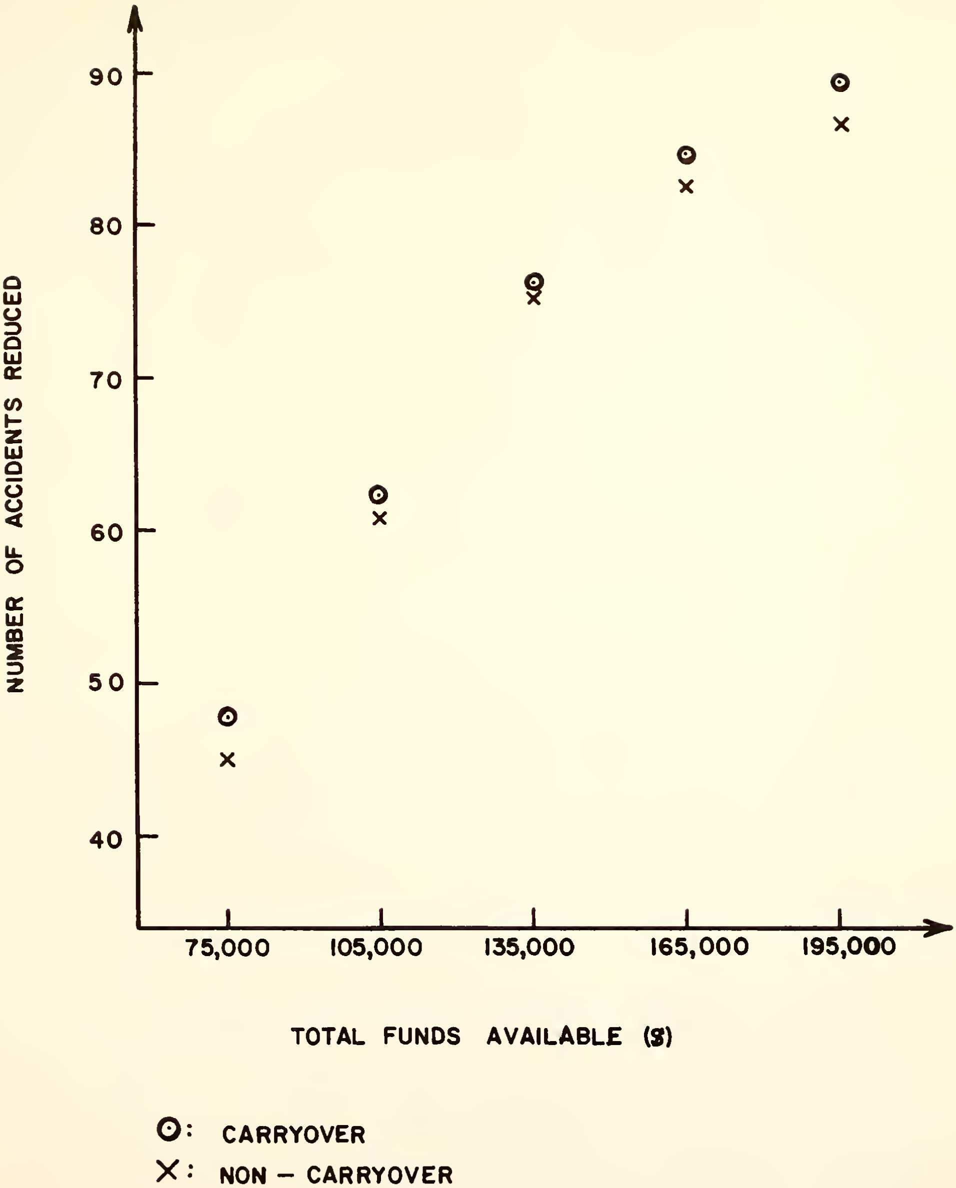


Figure 4.5. Number of Accidents Reduced and Total Funds Available (θ = 1.10)

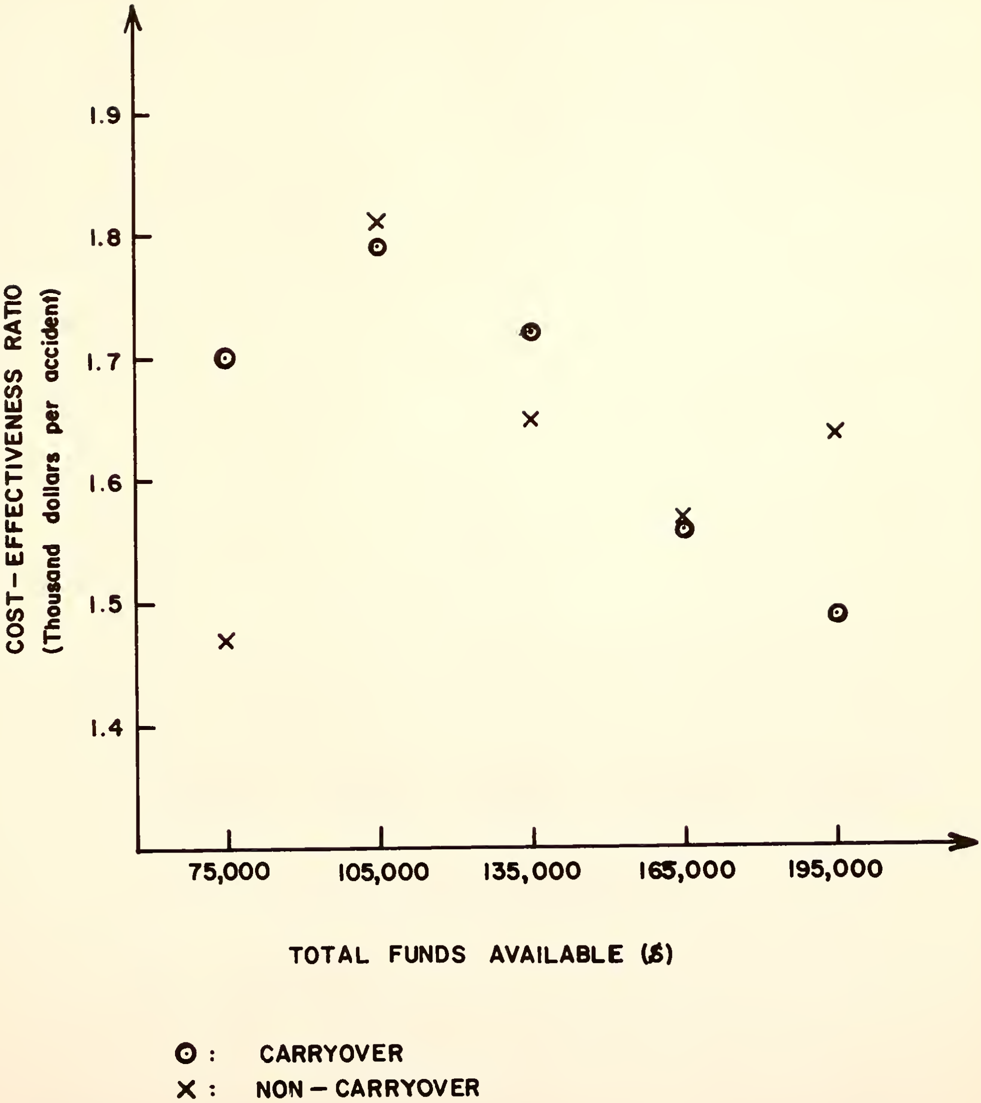


Figure 4.6. System Cost-Effectiveness Ratio and Total Funds Available (θ = 1.10)

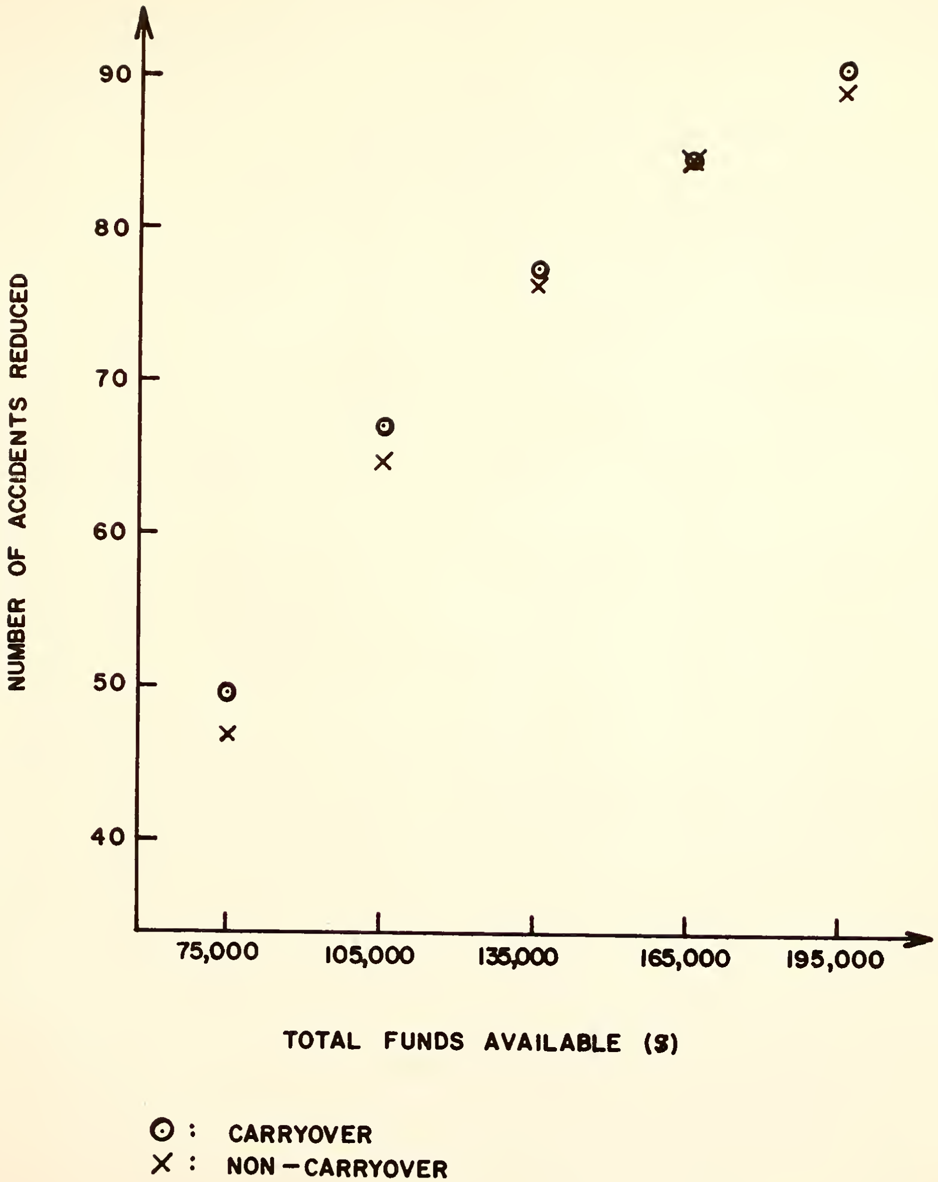


Figure 4.7. Number of Accidents Reduced and Total Funds Available ($\theta = 1.15$)

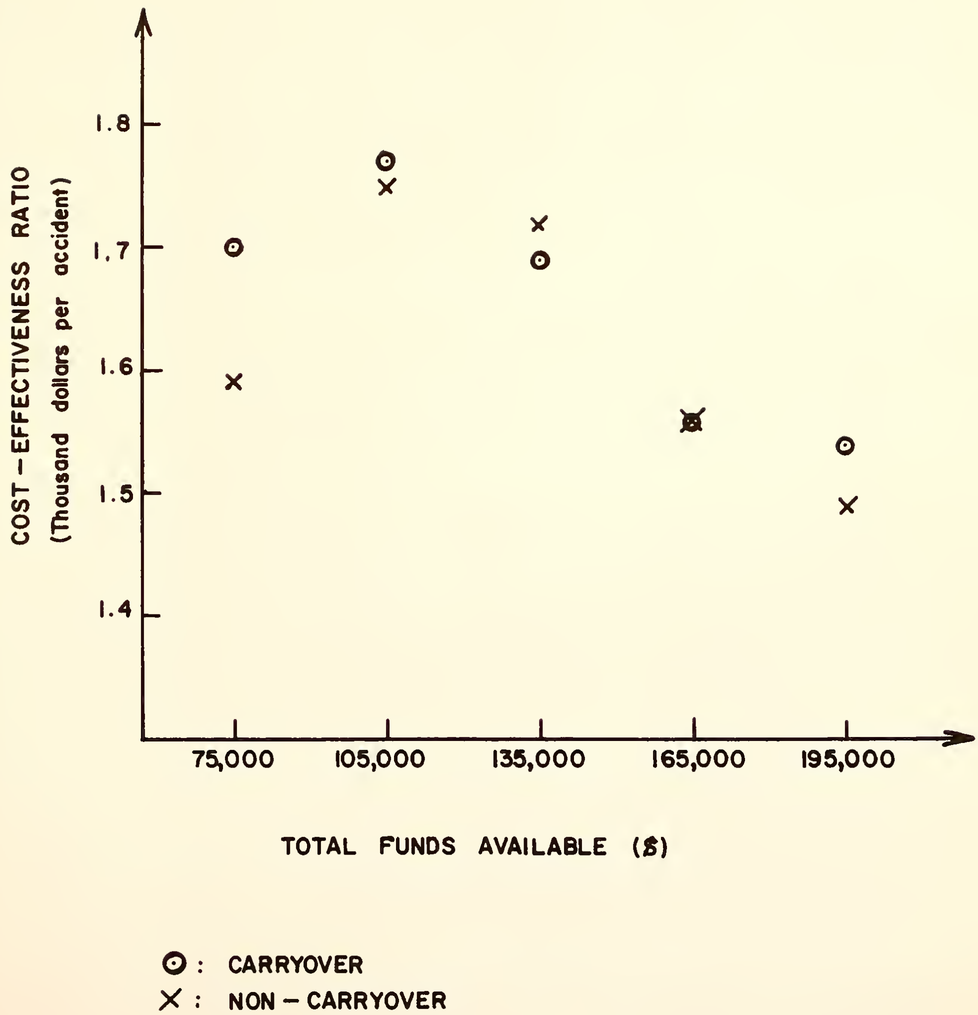


Figure 4.8. System Cost-Effectiveness Ratio and Total Funds Available (θ = 1.15)

Based on the above results, the following observations are made:

1. Budget carryover flexibility invariably increases the total number of accidents that can be reduced under a given budget ceiling (except in two cases where the number of accidents reduced equal to those under non-carryover model). However, this flexibility does not necessarily result in a lower cost-effectiveness ratio.
2. Although cost overrun was allowable in all runs (θ = 1.05 to 1.15), no cost overrun is present for the three higher budget scenarios and the total cost of safety program is less than the total budget available.
3. For a given budget ceiling, higher θ value increases the total number of accidents reduced but does not necessarily lead to a lower cost-effectiveness ratio.
4. As budget ceiling increases (in $30,000 increment), the total cost of safety program increases at a decreasing rate. The total cost appears to be stable in between budget scenarios $135,000 and $165,000.
5. Under each cost overrun level studied, the highest cost-effectiveness ratio is associated with the budget scenario B = $105,000 (except the non-carryover case at θ = 1.05). From that point,

cost-effectiveness ratio actually drops with increasing budget ceiling. This suggests that the budget scenarios studied in this example problem are probably within the economy of scale.

CHAPTER V

SUMMARY AND CONCLUSIONS

5.1. Conclusions.

In the following paragraphs a summary of the research study and a set of conclusions are presented.

1. Since 1974 accident severity rates in the State of Indiana have remained almost stable , and it appears that any further incremental improvement in traffic accident rates needs a careful and systematic evaluation and implementation of safety projects.

2. The safety improvement project evaluation should put more emphasis on cost-effectiveness approach than on benefit-cost analysis. Cost-effectiveness approach is more appropriate because it can incorporate non-priceable secondary effects with direct safety impacts of highway improvements.

3. In this study an evaluation methodology for cost-effectiveness analysis has been presented. A statistical testing procedure to evaluate the reduction effect of safety improvement projects has been discussed. Final output of the cost-effectiveness approach is a matrix which summarizes necessary data for decision making.

4. To demonstrate the use of the evaluation methodology developed in this research, an example using the accident data (1963-1972) from the State of Indiana has been presented.

5. On the basis of available data, modernization of signal or flashing beacon (change signal face, change timing, left turn arrow added, and so on) was found to provide most cost-effectiveness results. Sign and combination of sign and other improvements also showed adequate cost-effectiveness.

6. The data analysis indicated that reduction effects of single safety improvement projects are lower than those due to double safety improvement projects. However, the triple safety improvement projects did not produce higher reduction rates than the single and double improvement projects. The reason for this may be data deficiency and the complex interaction of the different safety improvement elements.

7. A modeling approach was developed to determine optimal budget allocation for selecting and programming different safety improvement projects. The model formulation included a basic model and a multi-year model with and without the flexibility of incorporating carryover of funds. Finally, a stochastic version of the models was formulated to include the uncertainty in estimating cost and accident reduction parameters. The objective function of the models considered the reduction of total accidents and the major constraint considered was the funding level.

8. A set of hypothetical examples was provided to illustrate the use of the models. The model results can also be used to determine the optimal funding level in order to

maximize cost-effectiveness of an areawide safety improvement program.

9. The stochastic version of the multi-year model can be successfully used to answer the question, "What, when and where safety improvement alternatives be implemented in order to maximize the reduction of total accidents on an areawide basis, subject to the total funding constraint?"

5.2. Suggestions for Further Research.

Further research in the subject would involve the following items.

1. The accident data used in the example problems included in this study were not sufficiently large and many safety improvement types could not be included in the analysis. Further research should involve collection of more comprehensive data covering longer periods of survey.

2. Further work is necessary to develop appropriate evaluation criteria involving both safety and secondary effects.

3. The optimal budget allocation model should be applied to real world situations.

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APPENDIX

TABLE A.1.

TRENDS IN HIGHWAY TRAFFIC ACCIDENTS AND SAFETY PROGRAM FUNDS IN THE STATE OF INDIANA

Year	No. of Accidents				No. of Persons		Estimated Vehicle Miles (millions)	Accident Rate (accident per 100 million vehicle miles)			Budget Safety Program	
	Total Accid.	Fatal Accid.	Injury Accid.	Property Damage	Total Killed	Total Injur.		Total	Fatal	Injury	In Current Dollars	In 1978 Dollars
1966	169,276	1,287	47,033	120,956	1,566	71,929	26,398	641.2	4.88	178.2	275,039	879,446
1967	175,886	1,320	47,296	127,270	1,570	71,679	28,351	620.4	4.66	166.8	248,346	643,216
1968	182,392	1,283	48,717	132,392	1,519	73,385	29,363	621.2	4.37	165.9	318,772	771,607
1969	205,006	1,413	51,996	151,597	1,676	77,970	31,900	642.7	4.43	163.0	244,587	527,900
1970	202,880	1,332	50,844	150,704	1,563	75,931	32,580	622.7	4.09	156.1	303,530	623,923
1971	194,607	1,353	50,370	142,884	1,611	73,337	35,430	549.3	3.82	142.2	328,313	555,772
1972	205,931	1,333	49,346	155,252	1,555	71,597	37,110	554.9	3.59	133.0	315,953	552,918
1973	206,490	1,332	49,268	155,890	1,605	70,850	38,030	543.0	3.50	129.6	263,334	445,775
1974	198,319	1,056	46,379	150,884	1,231	66,285	37,410	530.1	2.82	124.0	338,879	419,951
1975	195,672	983	47,752	146,937	1,133	68,883	37,880	516.6	2.59	126.1	363,913	420,774
1976	194,822	1,090	48,166	145,566	1,262	69,160	39,480	493.5	2.76	122.0	301,500	424,394
1977	213,739	1,085	50,639	162,015	1,256	*66,319	41,140	519.5	2.63	123.1	244,606	312,084
1978	225,779	1,143	52,335	172,301	1,314	74,420	42,870	526.7	2.66	122.1	426,302	426,302
Total	2,731,106	17,276	683,540	2,030,290	20,372	--	482,647	565.9	3.58	141.6	--	7,004,062

* Does not include Toll Road

Source: References 3 and 4.

Year	INDIANA HIGHWAY Bid Price Index (FHWA)
1966	95*
1967	100
1968	111*
1969	120*
1970	126
1971	153
1972	148
1973	153
1974	209
1975	224
1976	184
1977	203
1978	259

* Estimated by regression equation

$Y = 0.5098 \exp [0.0792\ T]$ $(R^2 = 0.8755)$

T: last two numbers in a year

Y: Indiana highway bid price index (estimates)

Table A.2 Indiana Highway Bid Price Index

Table A.3. Number of Locations by County.

Code	County	Number of Locations
1.	Adams	1
2.	Allen	8
3.	Bartholomew	1
4.	Benton	1
5.	Blackford	1
6.	Boone	1
9.	Cass	2
10.	Clark	3
16.	Decatur	1
18.	Delaware	4
20.	Elkhart	7
22.	Floyd	1
25.	Fulton	2
26.	Gibson	3
27.	Grant	3
28.	Greene	1
29.	Hamilton	6
30.	Hancock	1
32.	Hendricks	1
33.	Henry	1
34.	Howard	7
35.	Huntington	3
37.	Jasper	1
41.	Johnson	6
43.	Kosciusko	2
45.	Lake	16
46.	LaPorte	6
47.	Lawrence	1
48.	Madison	3
49.	Marion	36

Table A.3, cont.

Code	County	Number of Locations
50.	Marshall	1
52.	Miami	2
53.	Monroe	2
54.	Montgomery	1
55.	Morgan	4
56.	Newton	4
64.	Porter	2
66.	Pulaski	1
68.	Randolph	3
69.	Ripley	1
70.	Rush	1
71.	St. Joseph	4
72.	Scott	1
75.	Starke	1
79.	Tippecanoe	6
80.	Tipton	3
82.	Vanderburgh	6
84.	Vigo	1
85.	Wabash	2
87.	Warrick	2
89.	Wayne	1
92.	Whitley	1
Total	Total	182

Table A.4. Esitmates of Improvement Service Life.

Improvement	Service Life
Channelization	15 years
Signals	15 years
Safety Lighting	15 years
Median Barriers	15 years
Flashing Beacons	10 years
Guardrail	10 years
Pavement Grooving	10 years
Signing (major)	10 years
Signing (minor)	5 years
Raised Pavement Markers	5 years
Guide Markers	5 years
Painted Stripes	2 years

Source: Reference 8 .

Table A.5. The Number of Data Locations by Survey Period Before and After Installation of Safety Improvements.

Survey Period After Installation of Safety Improvements	Survey Period Before Installation of Safety Improvements									
	6 months	10 months	12 months	14 months	19 months	20 months	24 months	30 months	36 months	total
112 days						2				2
6 months	2									2
10 months		1								1
12 months			73				87			160
14 months				2						2
19 months					1					1
24 months							12			12
30 months								1		1
36 months									1	1
total	2	1	73	2	1	2	99	1	1	182

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